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Using the Auditory Hazard Assessment Algorithm for Humans (AHAAH) With Hearing Protection Software, Release MIL-STD-1474E

by Paul D. Fedele, Mary S. Binseel, Joel T. Kalb, and G. Richard Price

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Human Research and Engineering Directorate, ARL

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14. ABSTRACT
The Auditory Hazard Analysis Algorithm for Humans (AHAAH) calculates the risk to human hearing of impulse noises, such as gunfire or airbag deployment. It achieves this by modeling the effects of the sound pressure wave from the free field, through hearing protection (if used), through the middle ear, and into the inner ear. The output of the algorithm is the number of auditory risk units (ARUs) associated with exposure to the given impulse sound. ARUs predict hearing damage; values over 500 ARUs for a 24-h exposure are likely to produce permanent hearing loss. AHAAH can account for the use of many different forms of hearing protectors. AHAAH models the effects of the hearing protector on the sound pressure wave and evaluates the risk of hearing damage in ARUs when hearing protectors are properly worn. The algorithm is implemented in computer software. This report is a user's manual for the AHAAH software release MIL-STD-1474E.

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1. Introduction

1.1 Auditory Hazard Assessment Algorithm for Humans (AHAAH)

The AHAAH is an electroacoustic model of the ear used to evaluate the hazard of impulse sounds to human hearing. The algorithm is implemented in computer software. It models the 95th percentile (most susceptible) human ear. It also applies a user-selected direction from which sound is incident on the ear; sound traveling toward the head along the interaural axis is a worst-case condition. The model calculates the auditory hazard of impulsive sounds by dynamically modeling their transmission from the free field, through hearing protection (if used), through the middle ear, into the inner ear, where noise-induced hearing damage typically occurs. The model includes an active auditory reflex, involving middle ear muscle contractions, which can occur in response to the arrival of an intense sound or in anticipation of the arrival of such a sound. The output of the model is in auditory risk units (ARUs), which are physically related to damage resulting from displacements of the basilar membrane in the inner ear. A total of 500 ARUs is the maximum allowable “dose” for occasional exposures within a 24-h period. Doses greater than 500 ARUs are predicted to produce permanent hearing loss. For daily or near daily occupational exposures, the limit should be reduced to 200 ARUs.

The AHAAH model was initially developed based on the mechanical and fluid dynamic properties of the ear. It includes wave motion analysis of the basilar membrane in the cochlea based on the Wentzel–Kramers–Brillouin wave dynamics method that, for many decades, has been widely and successfully used to solve wave function problems in quantum mechanics and solid-state physics. As detailed in appendix A, since the first version of the AHAAH model was created, AHAAH has been augmented several times to include additional input/output capabilities, to calculate additional physical characteristics of pressure-time waveforms, and to more stably analyze waveforms with more severe and unusual behaviors. However, the fundamental auditory risk model, including the acoustical engineering representations of the ear canal, the middle ear, and the cochlea, have not changed since the model was first created.

This release of AHAAH (1474E) incorporates the additional capability of evaluating auditory hazards when hearing protection is used. AHAAH applies electroacoustic models appropriate for a wide variety of different hearing protectors and combinations of hearing protectors. AHAAH allows calculations for conditions when (1) no hearing protection, (2) a good hearing protection device (HPD) (an earplug or an earmuff), or (3) double hearing protection (plug and muff) are properly fitted and worn. Many specific hearing protectors can be applied using average values of hearing protector performance or using values reduced by 1 standard deviation.

1.2 Overview

Digital pressure-time histories, recorded as specified in MIL-STD-1474E,* must be imported into the model. During this process, the user provides the sampling frequency (determined by the digitizer at the time of recording), edits the waveform to remove extraneous material, and calibrates it to the correct pressure level. The user then saves the edited waveform as an AHAAH analysis input file with an AHA file extension and a header containing detailed characteristics of the waveform.

To analyze a file with an AHA extension, the program is started, the AHA file is loaded, and risk analysis is run. Risk analysis options are warned or unwarned middle ear muscle response. The AHAAH program provides numeric output in ARUs and creates a movie showing the time-dependent displacement that the incident waveform produces along the inner ear's basilar membrane.

AHAAH contains precise acoustical engineering descriptions for a wide variety of HPDs. The acoustical engineering parameters for HPDs are determined from, and validated by, referenced measurements of HPD performance. AHAAH evaluates the performance of HPDs by dynamically calculating the transmission of the waveform through the HPD and determining the time-dependent waveform at the appropriate location under the HPD. AHAAH saves this new waveform under a modified file name as an AHA input file for subsequent risk analyses.

AHAAH imports and analyzes one pressure time history at a time. While AHAAH will perform two different auditory hazard analyses and calculate many physical characteristics of waveforms, the AHAAH program was kept simple and was not programmed to perform many different analyses without restarting and reloading the waveform. AHAAH does not perform screen-refreshes in all situations, and it cannot necessarily perform multiple analyses without requiring the user to possibly rename output files and reopen the waveform. These restrictions are emphasized throughout the tutorial material in this report.

AHAAH evaluates the impact of exposure to the entire pressure-time history from beginning to end. We refer to a single pressure-time history as an impulse because AHAAH evaluates it as one complete sound exposure, even if the history contains a series of pressure pulses.

AHAAH can accept pressure-time recordings in waveform audio (WAV) file format or in ASCII (American Standard Code for Information Interchange) file format. When input is in ASCII format, floating-point decimal values are read in a column. AHAAH accepts ASCII files with a single column representing a single impulse, or with multiple columns, arranged as in a spreadsheet, with each column representing a different impulse. For the typical case of a single impulse in a single column in an ASCII file, the waveform will be read in and displayed on the bottom of the screen with a header at the top of the screen. If the file contains multiple impulses, you will be asked to identify which column you wish to import.

* MIL-STD-1474E. *Department of Defense Design Criteria Standard Noise Limits*, in review.

2. Preparing the AHAAH Model and the Impulse Waveform

This section discusses the steps required to set up the AHAAH software and prepare data files for analysis. A boxed tutorial, which will lead the user through the required steps, is included. In general, the conventions for Windows* and mouse use are followed.

2.1 AHAAH Software Files Folders and Data Examples

All of the AHAAH files, folders, and data examples are publicly available. The enclosed compact disk (CD) includes the software files and folders needed to run AHAAH. It also includes examples of impulse sound data files used in the tutorial of this report. The AHAAH files, folders, and example data can also be downloaded from the U.S. Army Research Laboratory's Web site under the "Software" heading at <http://www.arl.army.mil/www/default.cfm?page=343>.

The distributed AHAAH software includes the following folders and files:

- **AHAAH Program Files (folder)**

  AHAAH_MIL_STD_1474E.exe – the AHAAH software program

  StandardSingle.txt – file required by the software for the single hearing protection analysis option

  StandardDouble.txt – file required by the software for the double hearing protection analysis option

  EarModel.jpg – file image used by AHAAH

  HPD Atten.txt – file containing hearing protection device coefficients and values

  HPD Atten Temp.txt – file containing further hearing protection device characteristic values

  man.coe – file required by the software; contains coefficients for the algorithm parameters for humans

  MAN.FIG – file containing figure used by AHAAH

  Image5.jpg – file required by the software to display the graphic of the MIL-STD-1474E standard hearing protector configurations

*Windows is a trademark of Microsoft Corporation, Redmond, WA.

Dat – folder with a subfolder directory containing sound propagation and hearing protector data used by AHAAH

Original Data files – folder containing example data files for this tutorial

- **Original Data Files (folder)**

  TestImpulse.txt – tutorial data file in ASCII text format

  TestImpulse.wav – tutorial data file in WAV format

  TestImpulse.aha – tutorial data file in AHA format, a format unique to AHAAH

  M16Rifle.wav – tutorial data file in WAV format

  Howitzer.wav – tutorial data file in WAV format

The physical analytical quantities that specify the performance of AHAAH are contained in the text file man.coe. The man.coe file is not intended to be directly edited by AHAAH users and, for use as intended in MIL-STD-1474E, shall not be altered. The menu structure of the AHAAH guides the user in selecting among the various available options that are summarized in the file. However, users who are familiar with electroacoustics, or users who are curious about the parameters that specify AHAAH performance, may be interested in identifying the parameters in man.coe. The parameter definitions and values in man.coe are provided in table C-1 of appendix C.

2.2 Preparing and Launching AHAAH

The AHAAH program may run from the enclosed CD; however, it is recommended that you copy the contents to a hard drive, flash drive, or other storage device. Leave all of the program files in the same folder, as the program will look for these files in the folder in which it resides. The Data Files folder contents are needed for the tutorial and may be placed anywhere.

Double-click on the AHAAH_MIL_STD_1474E.exe icon to launch the AHAAH software. AHAAH opens in a maximized program window with a graphic of the model, as shown in figure 1.

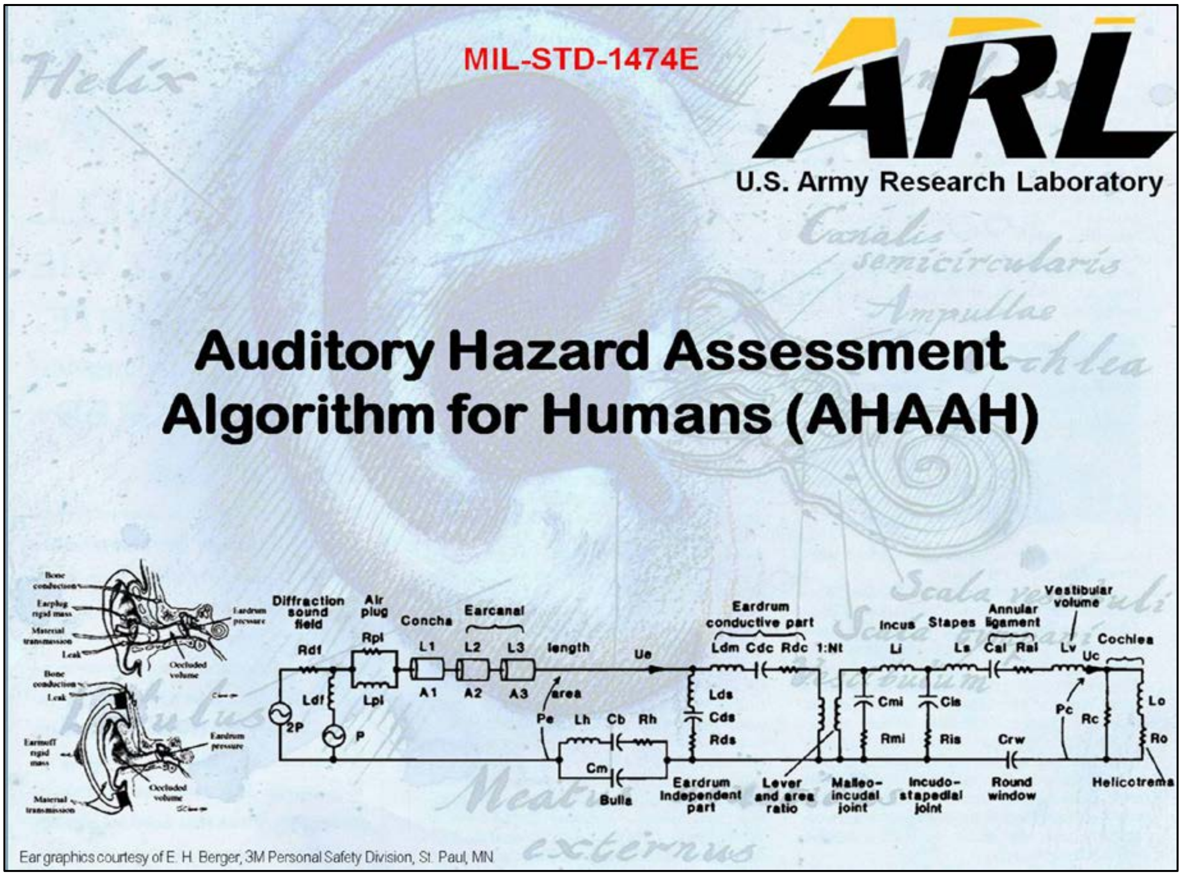


Figure 1. The screen that appears after starting the AHAAH software.

AHAAH is designed to run in a maximized program window. Windows 7 Enterprise users may encounter an error similar to the one shown in figure 2 when executing AHAAH.

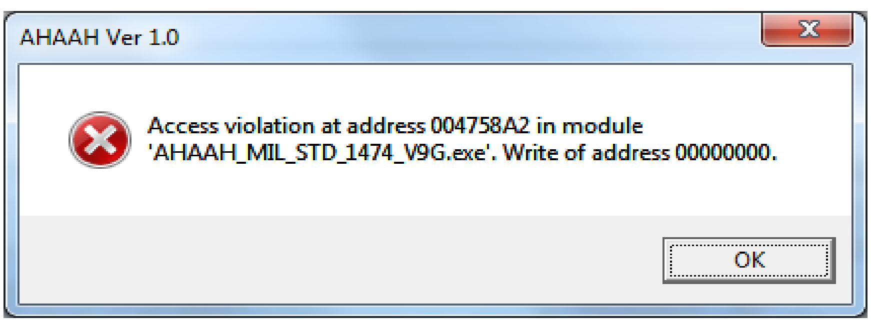


Figure 2. Error produced by AHAAH running under Windows 7 Enterprise.

If an error like this is encountered, close AHAAH and navigate to the AHAAH Program files directory. Right-click on the AHAAH executable (AHAAH_MIL_STD_1474E.exe) and select *Properties*. Select the *Compatibility* tab and check-mark the box for *Run this program in compatibility mode for:*, and in the drop-down box, select *Windows XP (Service Pack 3)*. Select *OK*. This should allow AHAAH to run with a Windows 7 Enterprise operating system.

If the AHAAH program is minimized and restored, the program window may not automatically restore. The AHAAH window can be restored by clicking on the AHAAH menu bar *File* pull-down menu, selecting the *Open AHAAH Waveform* command, and then cancelling the command.

2.3 Importing Files for Use

In order to be imported, edited, and analyzed by AHAAH, the data must have been collected in accordance with the provisions given in Requirement 3 of MIL-STD-1474E. These requirements call for:

- Units. Pressures shall be stored in units of pascals or sufficient information shall be provided to allow conversion to pascals.
- Data format. Pressures shall be stored in ASCII characters with no header or as WAV files.
- Sampling rate. The sampling frequency must be kept with the raw data or in a Readme file if required by the file format selected.
- File size. Individual raw data waveform files shall have a duration of no more than 1 s.

Measurement procedure:

- Single-impulse systems. The pressure history of the impulsive noise shall be obtained by producing one impulse at a time.
- Repetitive systems. A pressure history of the full range of noises produced by the system shall be recorded, e.g., a full 5-s burst from a 50-cal. automatic weapon, and individual pulses not to exceed 1 s shall be extracted from the series.

In order to be analyzed, raw data waveforms must first be imported into the AHAAH model. During this process they are edited to correct any baseline offset, trimmed to a suitable length, and adjusted in amplitude so the data are pressure-calibrated in pascals. Additionally, the start point for calculation is set, the ends of the pressure histories are tapered to minimize artifactual effects, and the sampling rate information is added to the headers. The model includes tools to facilitate these steps. Importation is complete when the waveform is saved as a file with the .aha extension. The steps of data importation are detailed in the following sections.

The raw data files must consist of files stored in the Windows WAV format or digitized pressure data stored in delimited floating-point decimal values in ASCII with no header text in the file.

When importing a waveform, the program will open windows that allow you to browse folders and select the file you wish to import. After a file has been selected, you will be asked questions about the file format.

Both types of files (WAV and ASCII) contain pressure-time histories that may not be calibrated with respect to specific pressure units. The raw data files typically do not contain calibration information, so when the data are collected it is imperative to collect information that can be

used to calibrate the waveform in pressure units. This could be either the peak pressure of the waveform, generally determined by use of a sound level meter providing output in decibels, or calibration data gathered by the use of a calibration device, such as a pistonphone, applied to the microphone used in data collection. These two methods are referred to in AHAAH as "calibrating to a known peak pressure" and "calibrating to a known source," respectively. If you use the "known source" method, you must determine the calibration factor before you start editing and analyzing your impulse data. See section 2.6.5 for information about determining the calibration factor. (Note: You must open your calibration waveform file and obtain the calibration information before you open your impulse data file.)

2.3.1 WAV Files

This file format is commonly used for recording music; thus, these are typically stereo files and contain a "right" and a "left" channel as well as a header. The header includes, among other things, the sampling rate (the same for both channels), which the AHAAH software automatically reads. When you import a WAV file, AHAAH imports both the left and the right channels and concatenates them into a single pressure-time waveform shown in the display. The left channel is displayed on the left of the screen beginning at time $t = 0$. The right channel is displayed on the right side of the screen as a function of continuing time after the end of the left channel. Calibration values are required for the left and the right channels. AHAAH's waveform-editing command, *Select Segment* (section 2.6.2), is used to separate the left and right channels for further analysis.

2.3.2 ASCII Files

Files stored in this format must not contain header information—just pressure data. You must know the sampling rate of the digitizer, which should be kept in a Readme file that is maintained with the pressure data file.

An ASCII file could be a single impulse or it might consist of several impulses arranged in columns, as in a spreadsheet. For the typical case of a single impulse, if the default answers to the questions are accepted, the waveform will be read in and displayed on the bottom of the screen with a header at the top of the screen. If the file contains multiple impulses, you will be asked to identify which column to import.

When *File* is selected in the menu bar, the following menu drops down (figure 3):

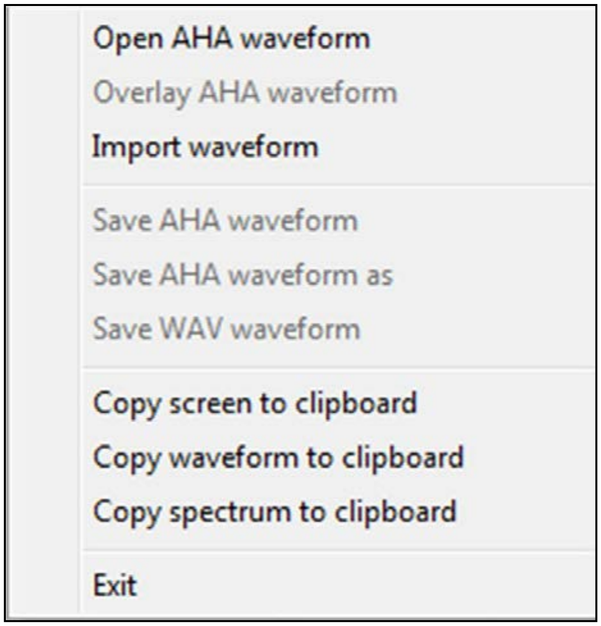


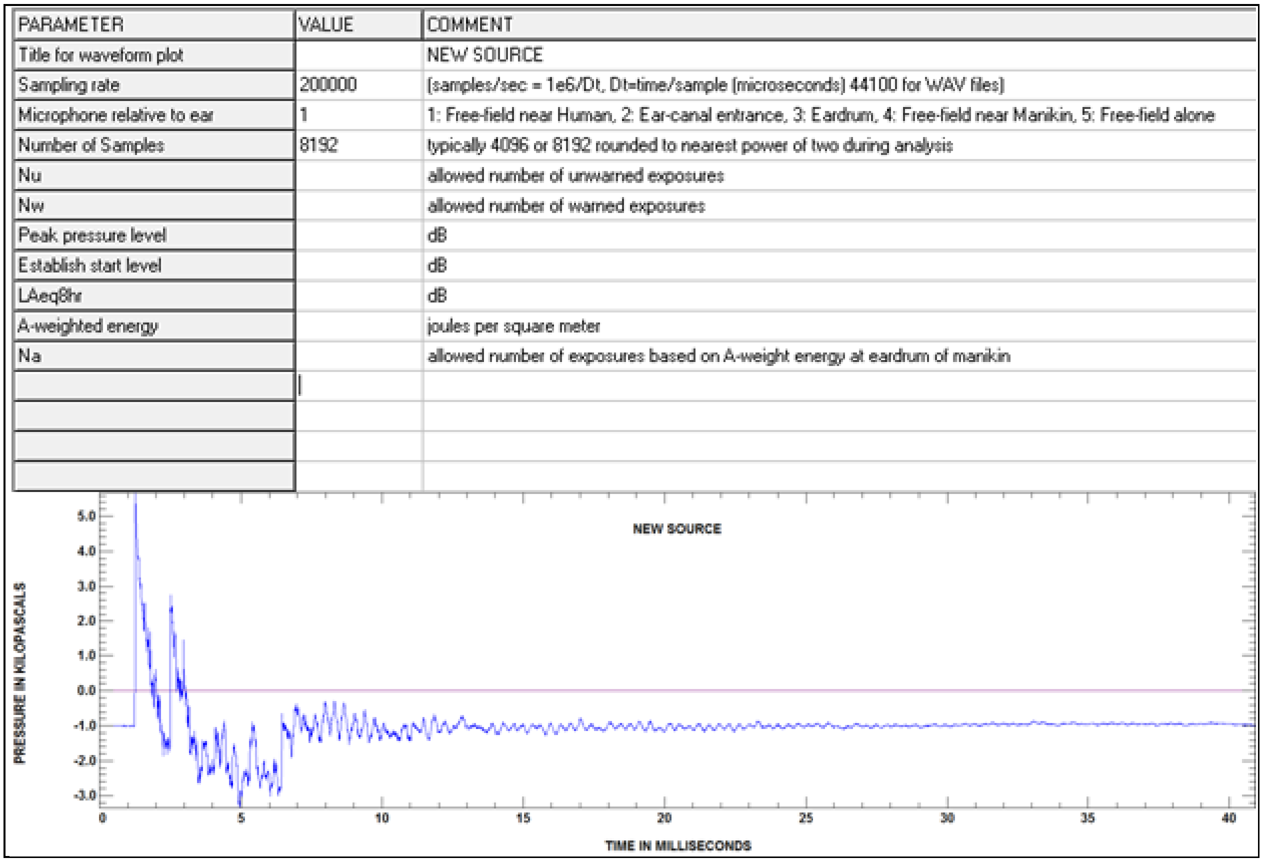
Figure 3. The pull-down menu that appears when selecting *File* from the AHAAH menu bar.

The *Copy* provisions (described in detail in section 3.2.4.2) in this menu allow the entire screen (waveform and header), just the waveform, or just the header (or the upper portion of the screen where AHAAH displays spectrum results) to be copied to the clipboard for insertion in documents, slides, etc.

Tutorial goal: Import a waveform stored in ASCII format. Select *File*, then *Import Waveform*.

1. Select the file TestImpulse.txt, which is in the folder Example Data Files.
2. Click the *Open* button.
3. Click the *YES* button or hit your *ENTER* key when asked if the data are in a spreadsheet.
4. The data are in a single column; therefore, select the *YES* button or hit your *ENTER* key to accept the 1 column default.

After the file TestImpulse.txt is imported, the window should appear as shown in figure 4.



PARAMETER	VALUE	COMMENT
Title for waveform plot		NEW SOURCE
Sampling rate	200000	(samples/sec = 1e6/Dt, Dt=time/sample (microseconds) 44100 for WAV files)
Microphone relative to ear	1	1: Free-field near Human, 2: Ear-canal entrance, 3: Eardrum, 4: Free-field near Manikin, 5: Free-field alone
Number of Samples	8192	typically 4096 or 8192 rounded to nearest power of two during analysis
Nu		allowed number of unwarned exposures
Nw		allowed number of warned exposures
Peak pressure level		dB
Establish start level		dB
LAeq8hr		dB
A-weighted energy		joules per square meter
Na		allowed number of exposures based on A-weight energy at eardrum of manikin

Figure 4. Screen view of imported waveform file TestImpulse.txt in AHAAH. (Image has been resized for legibility.)

Notice AHAAH has given the waveform the default title *NEW SOURCE* and a default sampling rate of 200,000 Hz, as shown in the header. The number of samples is shown to be 8192. Beneath this item, AHAAH lists several quantities that have not yet been calculated. As appropriate, these quantities will be calculated by AHAAH as the waveform is evaluated.

Tutorial goal: Change the name of the waveform.

1. Highlight the text in the *Title for waveform plot* row and *COMMENT* column.
2. Type *Sample Waveform*.
3. Press the *Enter* key.

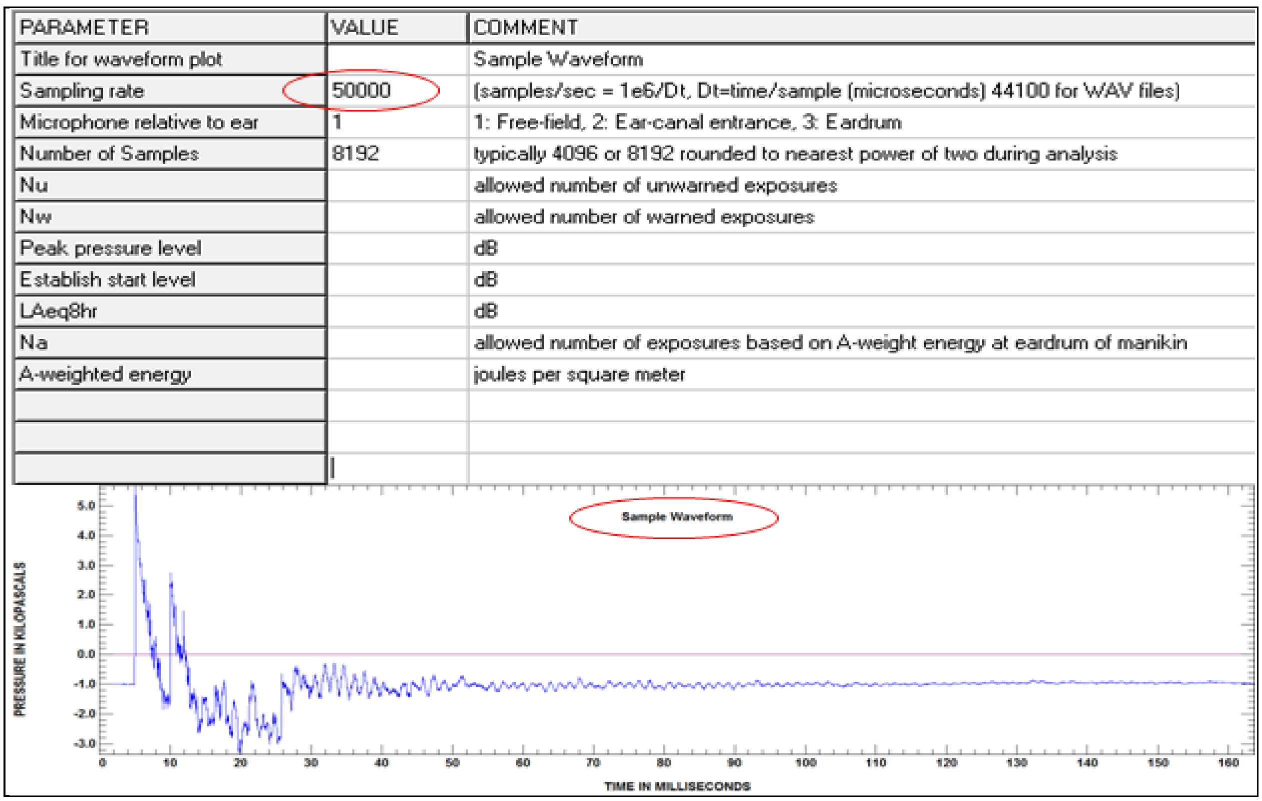
Note that the name of the waveform has been changed on the waveform plot in the lower panel.

2.4 Setting the Sampling Rate

For WAV files, AHAAH should have read the sampling rate from the header in the file. For ASCII files, a default sampling rate is assigned by AHAAH in order to display the waveform. It is critical that the sampling rate be set to the actual rate at which the data were collected. You should have this rate for your own recordings; for TestImpulse, the rate is 50,000.

> Tutorial goal: Change the sampling rate of the waveform.
>
> 1. Highlight the text in the *Sampling rate* row and *VALUE* column in the header area.
> 2. Type 50000.
> 3. Press the *Enter* key.
>
> The AHAAH window should now appear as shown in figure 5. Note the change in the x-axis scale (time).

When importing .txt files, AHAAH applies the default pressure unit, pascals, to the numbers in the text file. Although the default pressure unit is pascals, AHAAH plots the waveform in kilopascals as shown in figures 4 and 5.



PARAMETER	VALUE	COMMENT
Title for waveform plot		Sample Waveform
Sampling rate	50000	(samples/sec = 1e6/Dt, Dt=time/sample (microseconds) 44100 for WAV files)
Microphone relative to ear	1	1: Free-field, 2: Ear-canal entrance, 3: Eardrum
Number of Samples	8192	typically 4096 or 8192 rounded to nearest power of two during analysis
Nu		allowed number of unwarned exposures
Nw		allowed number of warned exposures
Peak pressure level		dB
Establish start level		dB
LAeq8hr		dB
Na		allowed number of exposures based on A-weight energy at eardrum of manikin
A-weighted energy		joules per square meter

Figure 5. AHAAH screen view of Sample Waveform after changing the waveform name and setting the sampling rate, as shown in the red-circled areas. (Image has been resized for legibility.)

2.5 Specifying Microphone Location

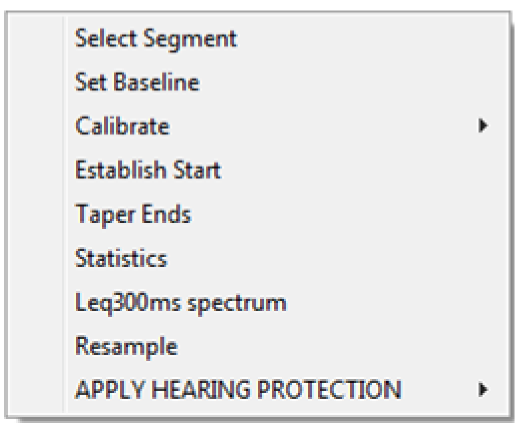
AHAAH allows the user flexibility in microphone location during data collection. There are three locations which are allowed: (1) *Free-field*, (2) *Ear-canal entrance*, and (3) *Eardrum*. Location 1, *Free-field*, refers to the hypothetical location where the ear of an exposed individual would be located. In order to perform an auditory hazard analysis, AHAAH must know where the recording was made. The default is 1, *Free-field*. You can change to another location by typing your choice (1, 2, or 3) in the *VALUE* column of the *Microphone relative to ear* row of the header. The choices are enumerated in the *COMMENT* column.

> TestImpulse.txt was recorded in the free-field near a human, so the microphone location does not need to be changed from the default selection, which is 1.

2.6 Editing the Waveform

An accurate AHAAH analysis requires the waveform to be edited before the analysis is run. Because some editing functions assume that the waveform was already corrected in some way, it is important to follow the editing steps in the order in which they are presented in the pop-up editing menu, with the exception of the *Resample* function which, if needed, is performed first.

A right-click anywhere below the menu bar within the AHAAH window opens the following pop-up menu:



Each of these functions is discussed in the following sections.

2.6.1 Resampling

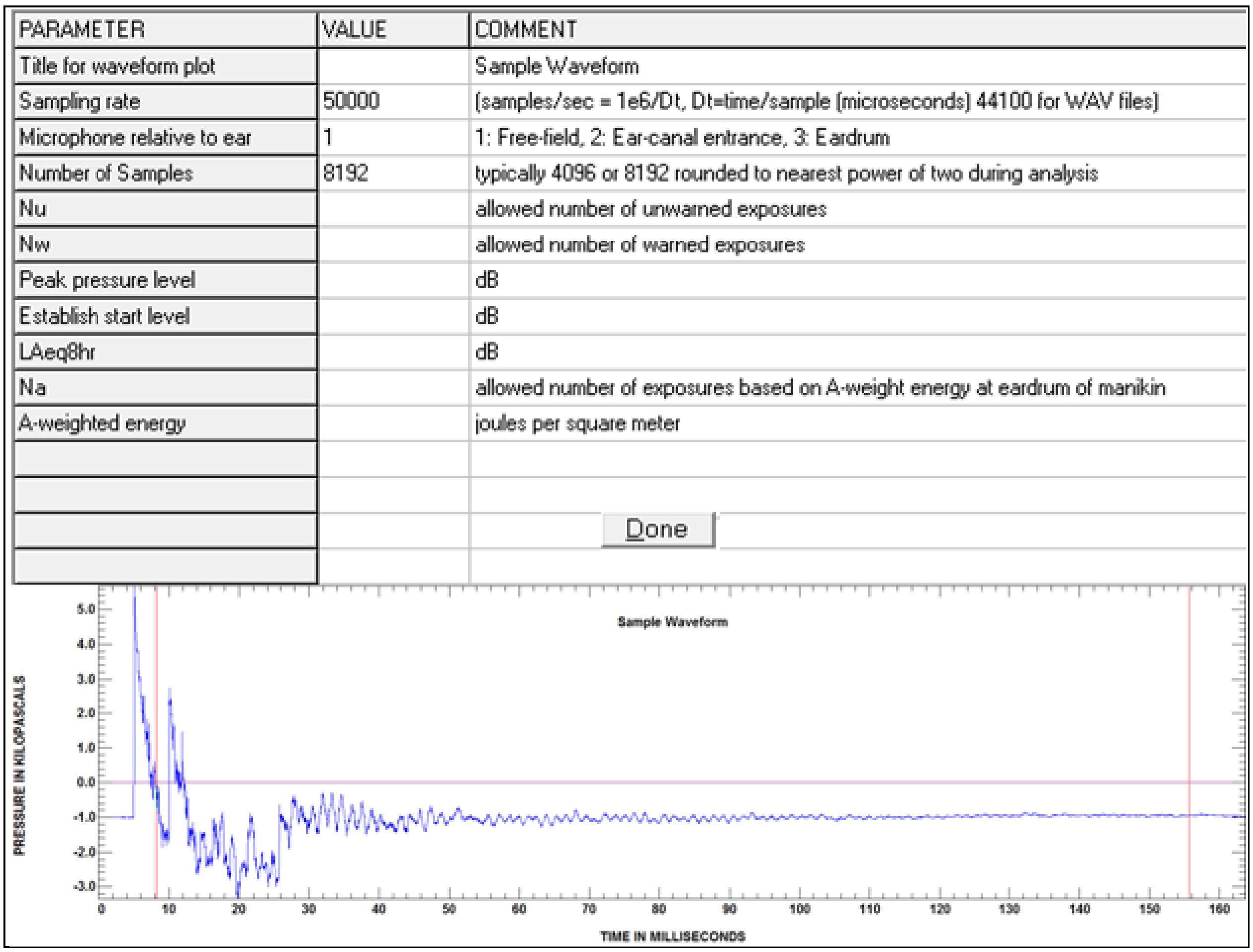
Clicking on *Resample* allows the user to resample the waveform at a higher or lower frequency. Resampling at a lower frequency is a way of reducing the number of points in the waveform. This is useful if the digitization rate is unnecessarily high and the waveform content remains unchanged at lower sampling rates. Basic Requirement 5.3.4.2 of MIL-STD-1474E specifies a minimum waveform sampling rate of 192 kHz when the data is recorded. Note that if the resampling rate is too low (below 40 kHz), important information may be lost, and the hazard

calculation may be spuriously low. Resampling at a higher rate increases the number of points but does not increase the amount of information in the waveform. If your data points are too close together for proper visual inspection, using this option may make editing the waveform easier because it will “spread out” the waveform plot.

TestImpulse.txt does not need to be resampled.

2.6.2 Selecting the Appropriate Segment

The data file may include information from before and after the impulsive event(s) of interest (e.g., from when the recording device was turned on until an impulse event). *Select Segment* is used to discard these extraneous data. When *Select Segment* is chosen, two selector red bars appear in the plot, which can be positioned to bracket the portion of the plot which is of interest (figure 6).



PARAMETER	VALUE	COMMENT
Title for waveform plot		Sample Waveform
Sampling rate	50000	(samples/sec = 1e6/Dt, Dt=time/sample (microseconds) 44100 for WAV files)
Microphone relative to ear	1	1: Free-field, 2: Ear-canal entrance, 3: Eardrum
Number of Samples	8192	typically 4096 or 8192 rounded to nearest power of two during analysis
Nu		allowed number of unwarned exposures
Nw		allowed number of warned exposures
Peak pressure level		dB
Establish start level		dB
LAeq8hr		dB
Na		allowed number of exposures based on A-weight energy at eardrum of manikin
A-weighted energy		joules per square meter
		Done

Figure 6. AHAAH screen image showing *Select Segment* bars used to select the important part of the waveform. (Image has been resized for legibility.)

The bars can be “dragged” (by left-clicking and holding as the bar is dragged) and “dropped” (by releasing the mouse button) at any location in the waveform. (The left selector bar is on the far left of the window and may not initially be visible; left-clicking and holding then dragging on the left edge of the plot area will move the red line and make it visible.) When the mouse is left-clicked, the bar closest to the mouse pointer will also jump to the location of the mouse, and the bar can be further dragged from that point. As the bars are moved, the *Number of Samples* entry in the header changes to indicate the number of samples contained in the selection between the bars. Moving the bars off the chart will select the entire waveform. When the *Done* button (which appears after *Select Segment* is chosen) is left-clicked, the plot area is redrawn, displaying only the section selected. The nonselected portion of the waveform is discarded. This procedure can be repeated as often as necessary to select a smaller segment of the waveform to be analyzed.

The waveform in TestImpulse.txt includes only valid data points and may be left as is.

2.6.3 Setting the Baseline

If the digitized waveform contains a DC offset that is not part of the true acoustic pressure fluctuation data (sometimes deliberately induced in recording to maximize the digitizer’s dynamic range), it must be removed. When *Set Baseline* is clicked, an *Expand Selection* button and two selector bars appear on the waveform. (Again, the left selector bar may be located at zero time and may not be visible.) As with *Select Segment*, the bars should be dragged and dropped so that they bracket the general area of the waveform that is believed to contain the zero value of pressure fluctuations, i.e., the ambient pressure or the true acoustic baseline. The button *Expand Selection* should then be clicked. The area between the cursors expands to fill the screen, and the bars reappear along with a *Select* button. The bars can be repositioned as needed to better identify the true acoustic baseline. When the *Select* button is clicked, the program takes the average pressure between the bars, subtracts it from the entire waveform, and replots the baseline-corrected waveform.

Tutorial goal: Remove the DC offset included in TestImpulse.txt.

1. Select Set Baseline.
2. Drag and drop selector bars to bracket the portion of the waveform that includes the offset only. The offset is the zero value of pressure fluctuations, i.e., the ambient pressure or the true acoustic baseline. This pressure level is generally located at the far left side of the waveform, before any significant pressure fluctuations have occurred.
3. Click Expand Selection.
4. If necessary, move the selector bars again to refine the selected area to contain only the offset value.
5. Click Select.

AHAAH subtracts the selected pressure value from the entire waveform, and the AHHAH window should now appear as shown in figure 7. Note the waveform has shifted up along the y-axis (pressure) when compared to the original waveform (figure 4).

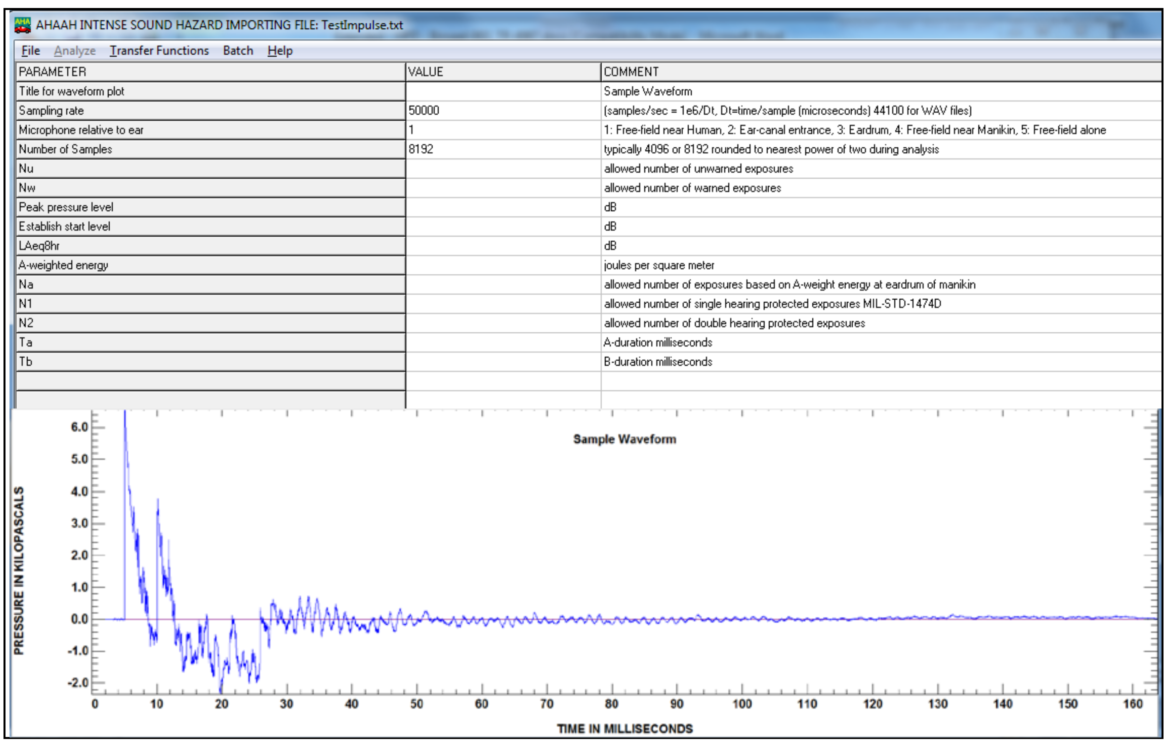


Figure 7. AHAAH screen view of sample waveform after removing the DC offset.

2.6.4 Statistics Command

The next step in importing most waveforms is to calibrate the waveform so its amplitude corresponds to the actual amplitude of the physical waveform of interest. In calibrating waveforms, the *Statistics* command is frequently used. Thus, before we discuss waveform calibration, we will describe the use of the *Statistics* command.

To evaluate many physical characteristics of the waveform, right-click anywhere in the lower panel of the AHAAH window to bring up the AHAAH right-click pop-up menu, and select *Statistics* from the menu shown in figure 8.

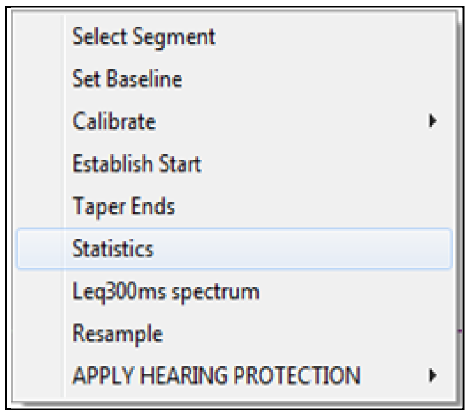
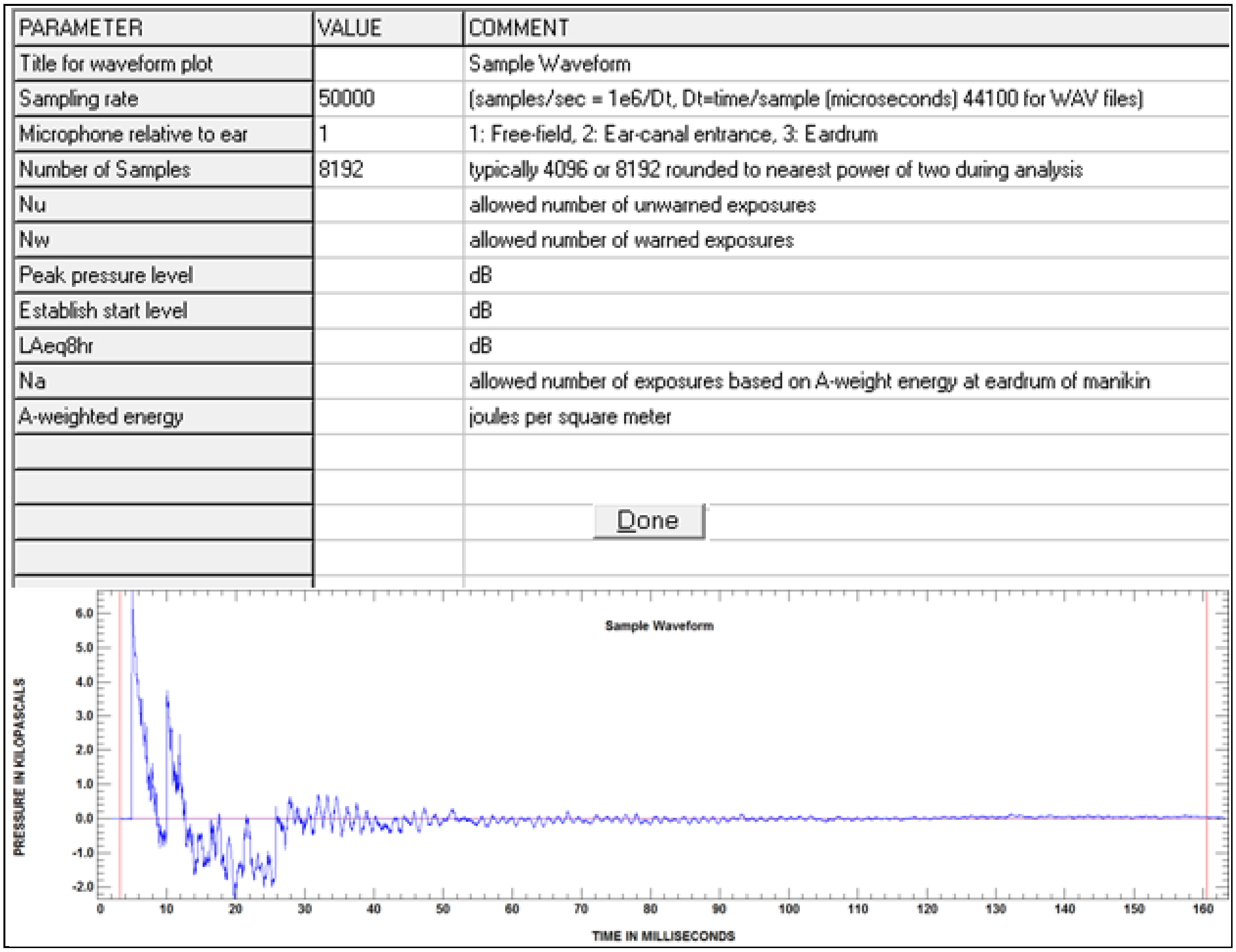


Figure 8. AHAAH pop-up menu showing the *Statistics* command.

Selecting the *Statistics* command puts two selector bars on the screen along with a *Done* button, as shown in figure 9.



PARAMETER	VALUE	COMMENT
Title for waveform plot		Sample Waveform
Sampling rate	50000	(samples/sec = 1e6/Dt, Dt=time/sample (microseconds) 44100 for WAV files)
Microphone relative to ear	1	1: Free-field, 2: Ear-canal entrance, 3: Eardrum
Number of Samples	8192	typically 4096 or 8192 rounded to nearest power of two during analysis
Nu		allowed number of unwarned exposures
Nw		allowed number of warned exposures
Peak pressure level		dB
Establish start level		dB
LAeq8hr		dB
Na		allowed number of exposures based on A-weight energy at eardrum of manikin
A-weighted energy		joules per square meter
		Done

Figure 9. Moveable red bars enclose the range for *Statistics* calculation. (Image has been resized for legibility.)

When the mouse is left-clicked and the bars are dragged-and-dropped, the values of five statistics for the selected segment of the waveform (the part of the waveform between the bars) are displayed in the header. In general, the mouse must be clicked, and at least one bar must be moved and dropped to allow AHAAH to display all five calculated values. The left bar can be moved all the way to the left, and the right bar all the way to the right, to evaluate the entire waveform. The values calculated with the *Statistics* command are shown in figure 10.

PARAMETER	VALUE	COMMENT
Title for waveform plot		Sample Waveform
Sampling rate	50000	(samples/sec = 1e6/Dt, Dt=time/sample (microseconds)) 44100 for WAV files)
Microphone relative to ear	1	1: Free-field near Human, 2: Ear-canal entrance, 3: Eardrum, 4: Free-field near Manikin, 5: Free-field alone
Number of Samples	8192	typically 4096 or 8192 rounded to nearest power of two during analysis
Number of exposures with no protector, warned		
Number of exposures with no protector, unwarned		
Peak Pressure Level	170.502	dB at 5.0 milliseconds
LAeq and Leq	142.488	dB equivalent A-wt level over time interval of 163.82 msec starting at 0.10 msec. Leq = equivalent Unweighted level = 149.973 dB.
LAeq8hr	90.035	dB equivalent A-wt level over 8 hours.
Na	0.312	allowed number of rounds based on A-weighted energy.
A-weighted energy	27.853	joules/m^2.

Figure 10. Waveform characteristics calculated by the *Statistics* command.

The *Statistics* command calculates the *Peak Pressure Level*, *LAeq* and *Leq*, *LAeq8hr*, *Na*, and *A-weighted energy*. Each value is described in the *COMMENT* column of the header, which also provides the level of equivalent unweighted energy over the specified duration of the evaluated waveform. The energy level values shown are frequently used in calibrating the waveform. The *Leq equivalent Unweighted level* shown in the *COMMENT* column is the root-mean-squared (RMS) level of a sinusoidal calibration waveform that has the same duration and contains the same total energy as the selected waveform.

Viewing statistics does not change the waveform.

Tutorial goal: Calculate and observe waveform physical values.

1. From the AHAAH right-click pop-up menu, select the *Statistics* command.
2. Move the red bars to select various portions of the waveform and observe the waveforms physical characteristic values over the selected sections.
3. Move the bars to the far right and far left to select the entire waveform.
4. Click on the *Done* button.

The screen will now look like figure 11.

PARAMETER	VALUE	COMMENT
Title for waveform plot		Sample Waveform
Sampling rate	50000	(samples/sec = 1e6/Dt, Dt=time/sample (microseconds) 44100 for WAV files)
Microphone relative to ear	1	1: Free-field, 2: Ear-canal entrance, 3: Eardrum
Number of Samples	8191	typically 4096 or 8192 rounded to nearest power of two during analysis
Nu		allowed number of unwarned exposures
Nw		allowed number of warned exposures
Peak pressure level	170.502	dB at 5.0 milliseconds
Establish start level	142.620	dB equivalent A-wt level over time interval of 158.94 msec starting at 1.66 msec. Leq = equivalent Unweighted level = 150.104 dB.
LAeq8hr	90.035	dB equivalent A-wt level over 8 hours.
Na	0.312	allowed number of rounds based on A-weighted energy.
A-weighted energy	27.853	joules/m^2.

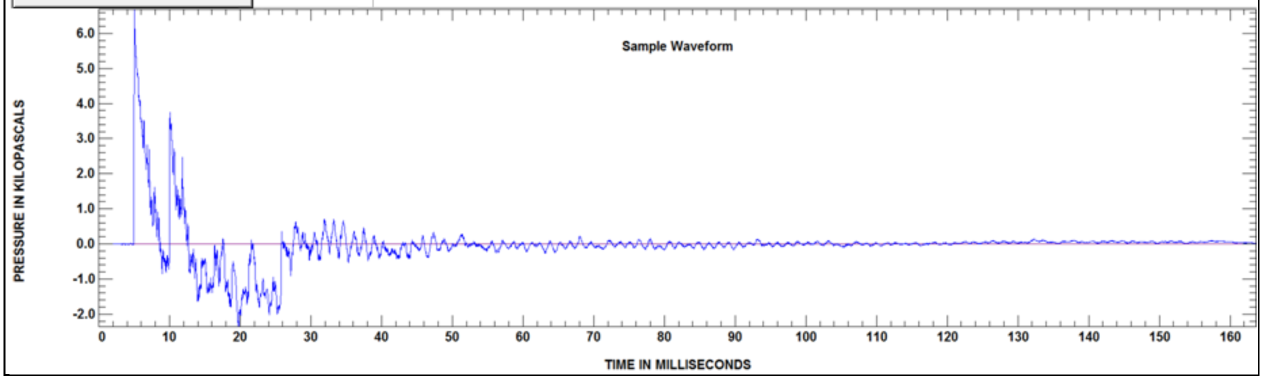


Figure 11. Screen and waveform physical characteristics calculated with the *Statistics* command. (Image has been resized for legibility.)

2.6.5 Calibration

Data values to be analyzed must be pressures in pascals, and the amplitude of the waveform must be properly calibrated. If the waveform data is not in pascals and/or is not calibrated, it must be calibrated to the correct units and/or values. There are two general approaches to calibrating the waveform: calibration to a known source and calibration to a known peak pressure.

Before beginning calibration, note that the output of condenser microphones is inverted (positive pressure downward). The AHAAH model is sensitive to the polarity of the pressure, which means that any inverted waveform needs to be reinverted for AHAAH to calculate the proper auditory hazard. If your waveform is inverted, reinvert it at this time; see the end of section 2.6.5.1 for information regarding how to accomplish this.

Note that if the *Set Baseline* feature is to be used, it must be done before calibration because changing the baseline affects peak pressures.

2.6.5.1 Calibrating to a Known Source

To calibrate to a known source, at the time of measurement a calibrated acoustic source is applied to the measuring microphone, and the output waveform recorded and stored as a digital file. Such sources typically produce a pure tone of 250 Hz (for pistonphones) or 1 kHz (for oscillator-driven calibrators). The RMS acoustic levels produced by these calibrators commonly

range from 94 to 124 dB. Given the recorded waveform and the known acoustic RMS pressure of the source, it is possible to determine an overall calibration factor for the full system and apply it to the waveforms subsequently recorded with it.

The calibration waveform should be imported via the *Import Waveform* menu option. A small section typical of the waveform should be selected (approximately 100 ms of data). A right click anywhere below the menu bar within the AHAAH window opens the AHAAH right-click pop-up menu. The *Statistics* command is selected, which puts two bars on the calibration waveform, selecting a section for evaluation. The bars can be moved so that most of the waveform is selected, and the statistics applicable to the section will appear in the header. The entry for *Leq equivalent Unweighted level* in decibels is the RMS level of the waveform (the algorithm treats the numbers as though they were pressures in pascals).

If the RMS level of the waveform differs from the known calibration level of the applied source, the data in subsequently measured waveforms must be corrected to properly represent the amplitude of the recorded waveforms. Specifically, the *Leq equivalent Unweighted level* for the calibration waveform should be subtracted from the nominal level of the calibrator. The data waveforms then need to be corrected by that number of decibels. Thus, a 114-dB calibrator whose output appeared to be 94 dB would require that levels in the data be adjusted upward by a change in decibel level, ΔdB, equal to +20 dB. This must be converted to a multiplication factor for correcting the pressure in pascals. Note that the change in decibel level is a logarithmic function, expressing in this case the ratio of the desired calibrated pressure to the recorded uncalibrated waveform pressure, i.e.,

$$\Delta \mathrm{dB} = 20 \log_{10}\left(\mathrm{P}_{\mathrm{cal}}/\mathrm{P}_{\mathrm{rec}}\right) \tag{1}$$

Therefore, the multiplication factor $\mathrm{P}_{\mathrm{cal}}/\mathrm{P}_{\mathrm{rec}}$ can be calculated from

$$(\mathrm{P}_{\mathrm{cal}}/\mathrm{P}_{\mathrm{rec}}) = \mathrm{antilog}_{10}(\Delta \mathrm{dB}/20) \tag{2}$$

or

$$(\mathrm{P}_{\mathrm{cal}}/\mathrm{P}_{\mathrm{rec}}) = 10^{(\Delta \mathrm{dB}/20)} \tag{3}$$

Following the example, for a desired increase of 20 dB, the multiplication factor is 10. Similarly, a change of –6 dB (a decrease of 6 dB) corresponds to a factor of 0.5.

To apply the multiplication factor, again right-click anywhere below the menu bar and select *Calibrate*, then *Multiply data by keyboard input* (figure 12).

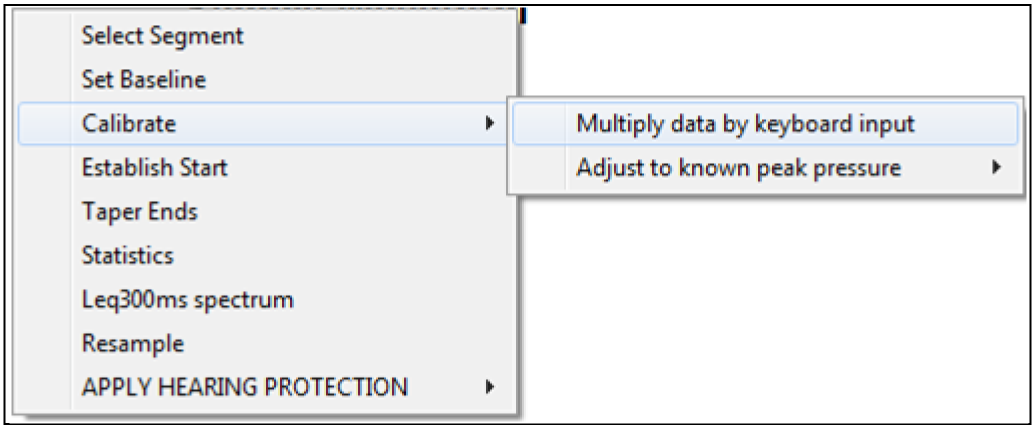


Figure 12. Selecting *Calibrate* - *Multiply data by keyboard input.*

After selection, a window will open where a numeric multiplier may be entered (figure 13).

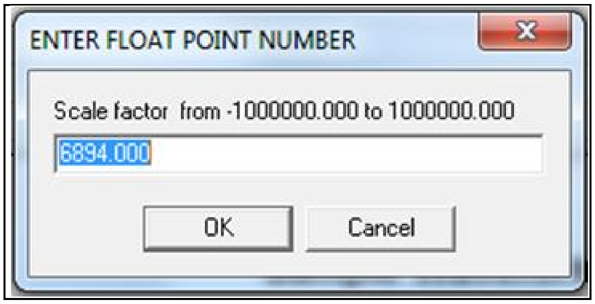


Figure 13. Entering a data multiplication factor.

The multiplier range is –1,000,000.000 to 1,000,000.000. The multiplier entered is applied when *OK* is clicked. Note that a negative multiplier inverts the waveform (a useful feature); multiplying by –1 flips the waveform over without changing its magnitude.

2.6.5.2 Calibrating to a Known Peak Pressure

For this method, at the time of measurement a calibrated instrument, such as a sound level meter, is used to measure the peak pressure level of the test waveform at the same location as the recording microphone. This datum can then be used to adjust the numbers in the digitized test waveforms so that the true peak pressure appears in the data.

If *Calibrate*, then *Adjust to known peak pressure* is selected, a submenu opens that allows the selection of one of nine sets of units (atmospheres, bars, peak pressure level in decibels, dynes per square centimeter, millibars [or hectopascals], kilopascals, or pascals, or PSI [pounds per square inch]) (figure 14).

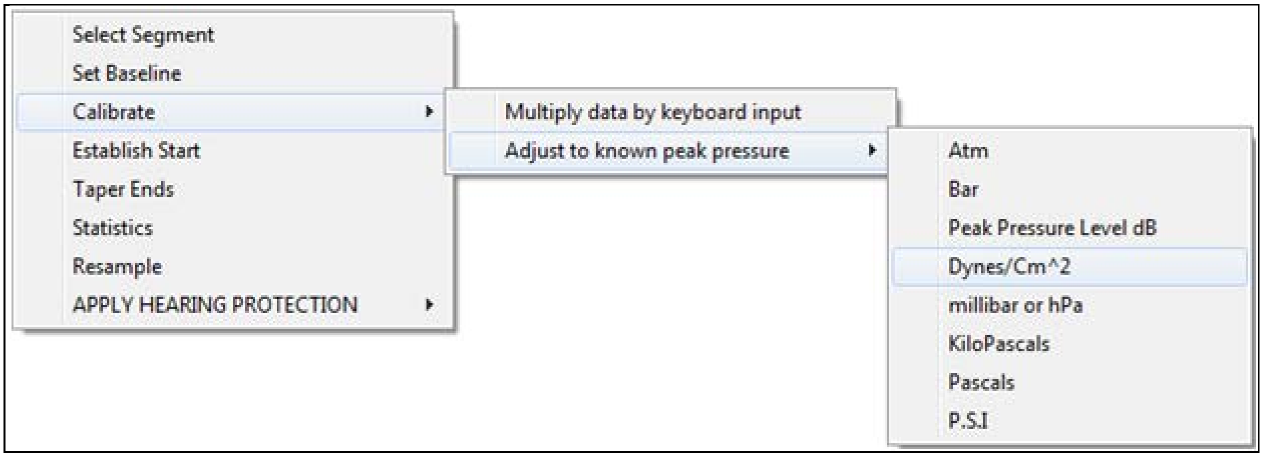


Figure 14. Selecting *Calibrate* **-** *Adjust to known peak pressure* **-** *Dynes/Cm^2*.

Select the units that were used to measure the peak pressure and enter the appropriate peak pressure in the window that opens (figure 15).

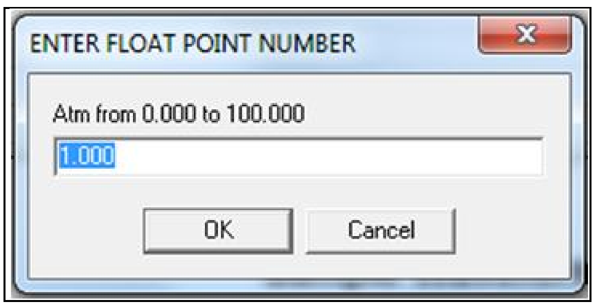


Figure 15. Entering the value for the known peak pressure. The units selected in this figure were atmospheres (atm).

When *OK* is clicked, the peak positive pressure in the waveform will be adjusted to the value entered in the units selected, all units will then be converted to pascals, and a plot will be generated in kilopascals. If the calibrated peak is negative, invert the waveform first, then adjust the peak value and reinvert it.

In the case of the Test impulse.txt file, measurements are already in pascals and properly calibrated; they can be left without adjustment.

2.6.6 Establishing the Analytical Starting Point for the Auditory Reflex

Before this editing function is run, it is important that the *Sampling Rate* (in the header) be set correctly; otherwise, the *Start* will be based on an incorrect estimate of timing. The user must also have calibrated the waveform before setting the start time because establishing the start involves an estimate of the stimulus intensity.

The human ear is more than a passive listening device. When exposed to intense impulsive sounds, the ear automatically responds by reflexively contracting muscles in the middle ear and stiffening the annular ligament, thereby reducing the energy entering the ear and partially protecting the cochlea. This process is called the auditory reflex. Measurements have shown that the auditory reflex is involuntarily initiated when a sound level reaches 134 dB. However, the auditory reflex can also be initiated before the arrival of a 134-dB sound pressure level if the exposed person anticipates the arrival of an intense noise. Examples of this are when an individual pulls the trigger to fire a weapon or when the impulse is immediately preceded by a distinct click or a warning signal, such as the flash that precedes the boom in an aerial fireworks display. There are also exceptions when firing weapons, such as when snipers use a disciplined trigger squeeze or when there is an unknown delay in weapon activation after the weapon has been triggered.

To accurately assess the risk of hearing damage from an impulsive noise, the initial condition of the auditory reflex must be taken into account. Further, since impulsive noises can last longer than it takes for the auditory reflex to fully stiffen the annular ligament, the state of the auditory reflex must be continuously evaluated throughout the ear’s exposure to the impulsive sound.

In regard to the auditory reflex, MIL-STD-1474E AHAAH applies two default exposure conditions: “warned” and “unwarned.” MIL-STD-1474E considers an exposure to be unwarned when the person whose ears are exposed does not know when to expect the impulsive noise. It considers an exposure to be warned when the person whose ears are exposed knows when to expect the impulsive noise. For an unwarned exposure, AHAAH begins to apply the auditory reflex when the waveform pressure first exceeds 134 dB. For a warned exposure, AHAAH analyzes the impact of the waveform with the auditory reflex fully applied throughout the entire duration of the impulsive waveform. If the triggering time of the auditory reflex is known, AHAAH also allows selection of the start time for the auditory reflex. You must determine if the sound exposure is warned or unwarned, or you can specify precisely when the auditory reflex should be initiated, if this information is known for your waveform.

The start time for the application of the auditory reflex is selected by applying the *Establish Start* command from the right-click pull-down menu.

2.6.6.1 Using *Establish Start*

When *Establish Start* is clicked, the program expands the waveform at the beginning of the file, places the selector bar at the default trigger point (the first data point at 134 dB or higher) and provides a *Done* button to confirm the start location. The screen is shown in figure 16.

PARAMETER	VALUE	COMMENT
Title for waveform plot		Sample Waveform
Sampling rate	50000	(samples/sec = 1e6/Dt, Dt=time/sample (microseconds) 44100 for WAV files)
Microphone relative to ear	1	1: Free-field, 2: Ear-canal entrance, 3: Eardrum
Number of Samples	8191	typically 4096 or 8192 rounded to nearest power of two during analysis
Nu		allowed number of unwarned exposures
Nw		allowed number of warned exposures
Peak pressure level	170.502	dB at 5.0 milliseconds
Establish start level	159.5	dB at 5.0 msec
LAeq8hr	90.035	dB equivalent A-wt level over 8 hours.
Na	0.312	allowed number of rounds based on A-weighted energy.
A-weighted energy	27.853	joules/m^2.
		Done

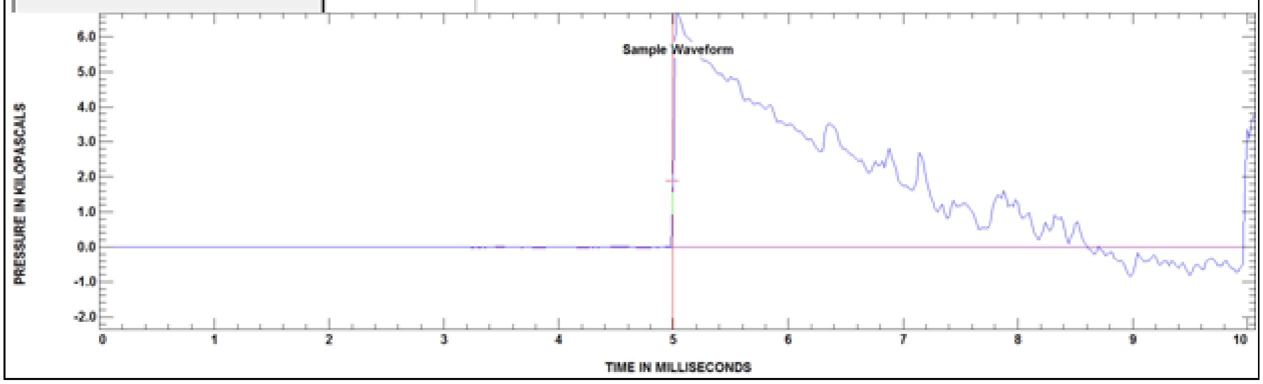


Figure 16. The *Establish start level* defaults to 159.5 dB. The red bar can be moved to select different start times.

The bar can be moved by dragging, and as it moves, the *Establish start level* entry in the header changes to reflect the sound pressure level at the cursor. If the waveform has a precursor pulse before the main impulsive front, it may be appropriate to place the *Establish Start* time at the time of the precursor. Also, if the impulse has a gradual buildup or does not exceed 134 dB until well after the first significant pressure fluctuations, it may be appropriate to move the *Establish Start* time further toward the beginning of the impulsive waveform. When the desired bar placement is achieved, click *Done*.

Note that to accurately analyze a waveform, AHAAH must begin calculations 5 ms before any significant pressure fluctuation. For impulsive waveforms, this normally means that AHAAH analyzes the waveform starting at 5 ms before the established start time. If there are not 5 ms of data before the start, AHAAH lengthens the waveform so that there is a 5-ms interval to the left of the bar location by adding data at 0 Pa.

Tutorial goal: View AHAAH's determination of the correct start point of the TestImpulse.txt impulse.

In the impulse in TestImpulse.txt, the start of the impulse is the nearly instantaneous rise to the peak pressure. AHAAH's calculated start point is acceptable.

1. Select *Establish Start*.

Note the location of the start cursor bar in the plot and the sound pressure level (in decibels) at this point (this information is in the header section)—159.5 dB, which is the first data point ≥134 dB. Small differences in the selected *Set Baseline* pressure value may cause small differences in the *Establish Start* level.

2. Select *Done*.

The *Establish Start* command is used with imported waveforms. In section 2.6.8, we will save a waveform as an AHA file. In an AHA file, the *Establish Start* time has already been set, either directly by the user or by default. Although the *Establish Start* command can still be called, the time of the *Establish Start* has been fixed and will not change. If the *Establish Start* command is called, a bar pointer will appear and it can be moved about the waveform. The header will update, but no change will actually occur in the *Establish Start* time.

2.6.7 Tapering the Ends

Artificial discontinuities may exist in the original data file (e.g., a discontinuity at the end of a data file when a microphone is turned off) or they may have been created during the editing process (e.g., discontinuities at the beginning and end of the waveform when *Select Segment* was performed). AHAAH interprets all points on the waveform as valid data, including any discontinuities at the start or end of the stored waveform. Artificial pressure discontinuities can lead to spuriously large estimates of auditory risk. Therefore, the waveform must be smoothly "windowed" to eliminate these artificial discontinuities. Left-clicking on *Taper Ends* puts two selector bars on the waveform along with a *Done* button. The bars should be placed just inside any discontinuity. When the *Done* button is clicked, the waveform outside the bars is tapered off by a cosine function. Leave as much of the waveform as possible inside the cursors, consistent with a tapering of the acoustic data. For some impulses, the parts of the waveform that look insignificant to the eye may nevertheless contain oscillations damaging to the ear. If the waveform is not tapered at the ends, then end-effect distortions can occur, generating an erroneous result.

Tutorial goal: Taper the ends of TestImpulse.txt to eliminate discontinuities.

In order to save as much data as possible, taper only the very last points of the impulse data.

1. Select *Taper Ends*.
2. Move the selector bars very near the ends of the waveform.
3. Select *Done*.

The AHAAH window should now appear as shown in figure 17.

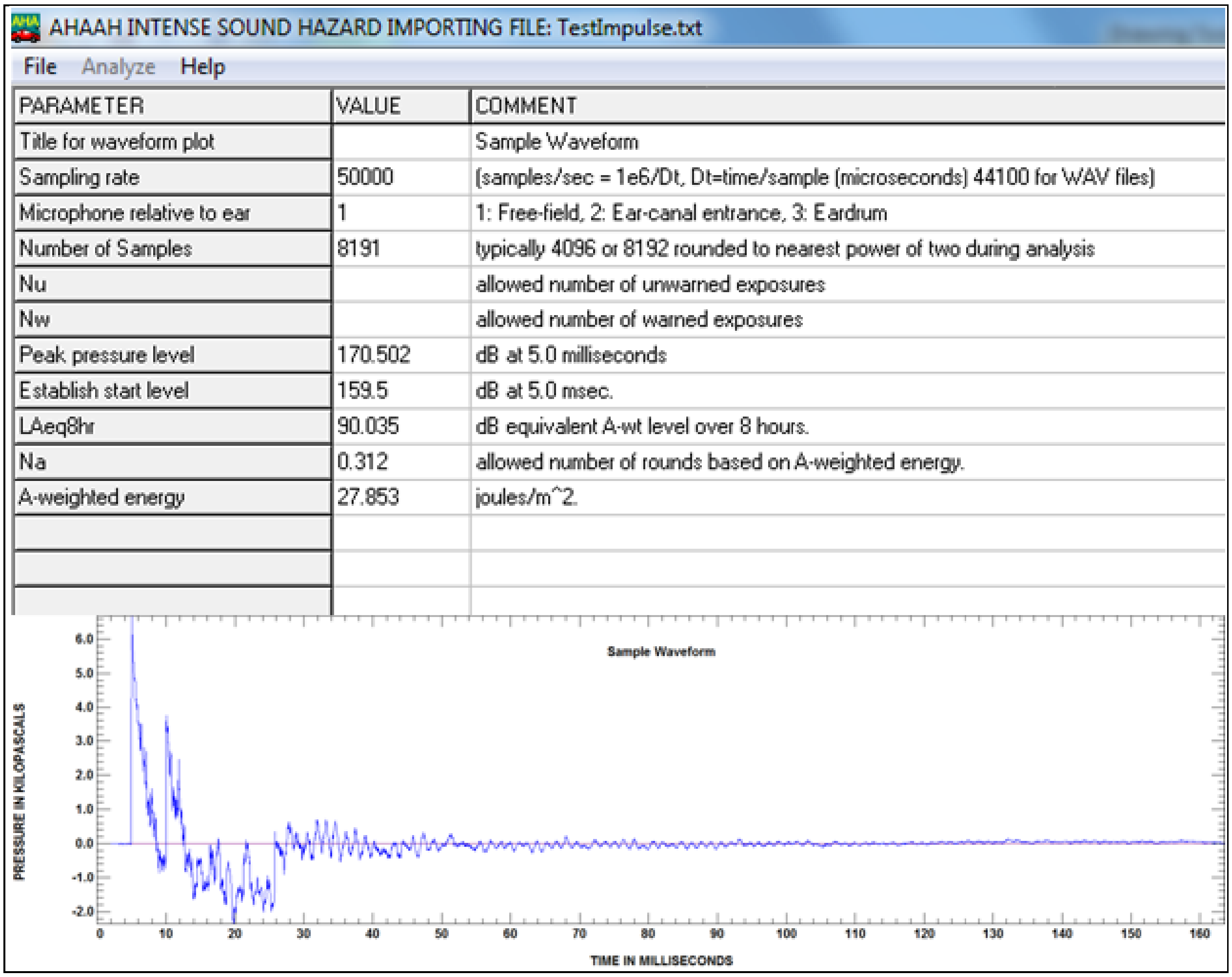


Figure 17. AHAAH screen view of sample waveform after completing waveform editing.

In general, the AHAAH header changes according to the function being performed at the moment. Thus, the specific values shown in the header will depend on which command was last issued. Notice that *Establish Start* changes the values displayed in the header. After selecting *Establish Start*, shown in figure 16, the *Establish start level* is shown under the *Peak pressure level* in the

header; but, as shown in figure 11, after selecting *Statistics*, LAeq and Leq are shown after *Peak pressure level*. To recover the values shown by the *Statistics* command, you can save the waveform as an AHA file, open the file, and recalculate the values using the statistics command. After saving the AHA file, the *Establish Start* time is fixed and can no longer be changed.

> Tutorial review: The specific editing steps that should have been taken are as follows:
>
> 1. In the header, set the sampling rate to 50,000 Hz.
> 2. Correct the baseline to remove the DC offset.
> 3. Establish the start at the leading edge of impulse.
> 4. Taper the extreme right and left ends of the waveform, leaving as much of the waveform for analysis as possible.

These four steps complete the preparation of a waveform for AHAAH analysis.

In figure 17, note that AHAAH has not yet been used to calculate the allowed numbers of warned and unwarned exposures associated with this waveform. Because AHAAH does not automatically save waveform edits and modifications, AHAAH does not perform auditory risk analyses on modified-but-not-saved waveforms. The *Analysis* item on the AHAAH menu bar is grayed-out and not accessible. Thus, when the previously mentioned four waveform editing processes are completed, the resulting waveform must be saved as an AHA file. The saved AHA file will then be opened to perform subsequent auditory risk analyses.

2.6.8 Saving the Edited Data File as an AHA File

Select *File*, then *Save AHA Waveform As*. The file may have any Windows-legal name and is automatically given the AHA extension when saved. For mathematical considerations, the waveform is also expanded in length to a size that is a power of 2 (if it is not already a power of 2). It may be stored in any directory you choose and may be opened for analysis when you click on *File*, then *Open AHA Waveform*.

> The edited waveform has already been saved as TestImpulse.aha.

2.6.9 Other Sample Files

The *Data Files* included with this standard includes two WAV files not discussed thus far: *Howitzer* and *M16Rifle*. They are included for practice in working with WAV files and with calibrating to a known source. Remember that AHAAH reads the sampling rate from WAV files, so you do not have to enter it.

The left channel of the *Howitzer* file contains a calibration signal (250 Hz at 124-dB RMS). The C-weighted level in the file is 149.8 dB. The actual calibration level should be 124 dB; therefore, the data in the measured waveform needs to be reduced by 25.8 dB (124–149.8 = –25.8 dB) for a multiplier of 0.05 (see section 2.6.5.1). Once calibrated, the right channel contains only low-

amplitude digitizer noise, in which one can easily see the “stepped” waveform that results at the digitizer’s limits at its low end. This channel contains no usable data.

In the *M16Rifle* file, both channels contain data from a single firing of an M16 rifle. The microphones were approximately colocated at the position of a shooter’s ear. The left channel was recorded underneath an earmuff-style hearing protector, which had been placed on an acoustical test fixture (mannequin). The right channel was recorded outside the earmuff. If you recorded this file, you would have determined the peak pressure for each of the channels at the time of recording or have recorded calibration signals as in the previous case. For this example, we will let the known peak pressure of the right channel be 165 dB and that of the left be 140 dB. The recordings were also made with an inverting microphone; positive pressures are recorded as negative values.

To analyze these waveforms, they must be inverted by multiplying by –1, and then they must be separated using the *Select Segment* command. The following tutorial steps show how to separate, calibrate, and save these WAV file recordings.

Tutorial goal: Open, separate, name, calibrate, properly locate, and save the left channel recording in the M16Rifle.WAV file.

1. Click AHAAH's *File* drop-down menu.
2. Select *Import waveform*.
3. Select the file: M16Rifle.WAV.
4. Click *Open*.
5. Select *Calibrate - Multiply data by keyboard input*, enter –1, and click *OK*.

The original waveform is now properly inverted so that positive pressure values are shown as positive decibel values.

6. Change the title of the waveform to M16Rifle_Under_the_Muff
7. Use the *Select Segment* command to select the left portion of the waveform, from 0 to 50 ms.
8. Apply the *Statistics* command (section 3.1) (note the peak pressure in the waveform is 163.278 dB).

The peak pressure of this portion of the waveform should be 140 dB, so the decibel level must be reduced by a ΔdB = –23.278 dB.

9. Select *Calibrate - Multiply data* by keyboard input and enter 0.0685646, which equals $10^{(\Delta dB/20)}$ (see section 2.6.5.1, "Calibrating to a Known Source").
10. Click *OK*.

The *Statistics* command (section 2.6.4) can be used to verify that the peak pressure is now 140 dB.

The location of this pressure waveform is at the entrance of the ear canal.

11. Change the *Microphone relative to ear* location to 2 (ear-canal entrance).

The screen will appear as shown in figure 18.

PARAMETER	VALUE	COMMENT
Title for waveform plot		M16Rifle_Under_the_Muff
Sampling rate	48000	PCM Data, PCM, 16 bits per sample, Stereo
Microphone relative to ear	2	1: Free-field near Human, 2: Ear-canal entrance, 3: Eardrum, 4: Free-field near Manikin, 5: Free-field alone
Number of Samples	4096	typically 4096 or 8192 rounded to nearest power of two during analysis
Number of exposures with no protector, warned		
Number of exposures with no protector, unwarned		
Peak Pressure Level	140.000	dB
LAeq and Leq	115.191	dB
LAeq8hr	59.706	dB
Na	345.182	allowed number of exposures based on A-weighted energy under a protector
A-weighted energy	0.026	Joules/m^2
N1		allowed number of single hearing protected exposures MIL-STD-1474D
N2		allowed number of double hearing protected exposures
Ta		A-duration milliseconds
Tb		B-duration milliseconds

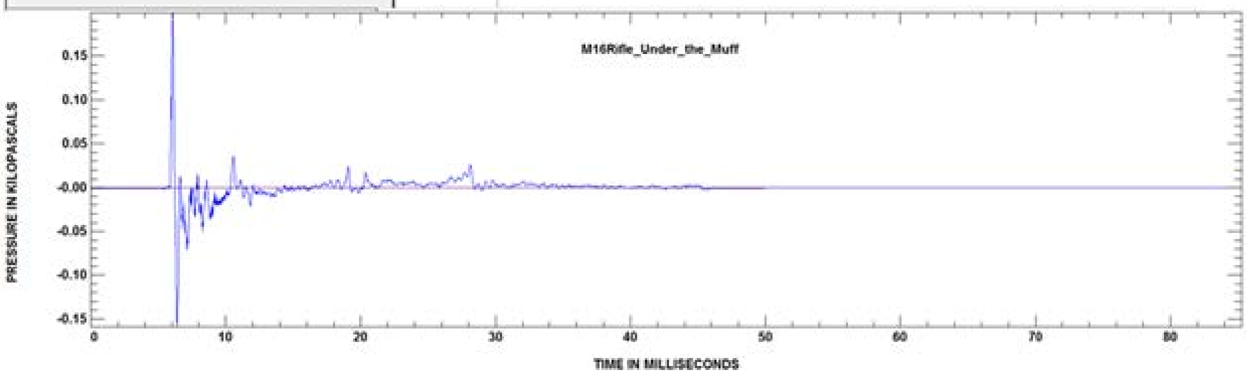


Figure 18. M16Rifle.WAV left channel, under the hearing protector muff.

Tutorial goal: Open, separate, name, calibrate, properly locate, and save the right channel recording in the M16Rifle.WAV file.

1. Click AHAAH's *File* drop-down menu.
2. Select *Import waveform*.
3. Select the file: M16Rifle.WAV.
4. Click *Open*.
5. Change the title of the waveform to M16Rifle_Outside_the_Muff
6. Select *Calibrate - Multiply data by keyboard input*, enter –1, and click *OK*.

The original waveform is now properly inverted so that positive pressure values are shown as positive decibel values.

7. Use the *Select Segment* command to select the right portion of the waveform, from 46 to 93 ms.
8. Apply the *Statistics* command (see previous tutorial note); note the peak pressure in the waveform is 168.577 dB.

The peak pressure of this portion of the waveform should be 165 dB, so the decibel level must be reduced by a ΔdB = –3.557 dB.

9. Select *Calibrate - Multiply data by keyboard input* and enter 0.663972, which equals $10^{(\Delta dB/20)}$ (see section 2.6.5.1, "Calibrating to a Known Source").
10. Click *OK*.

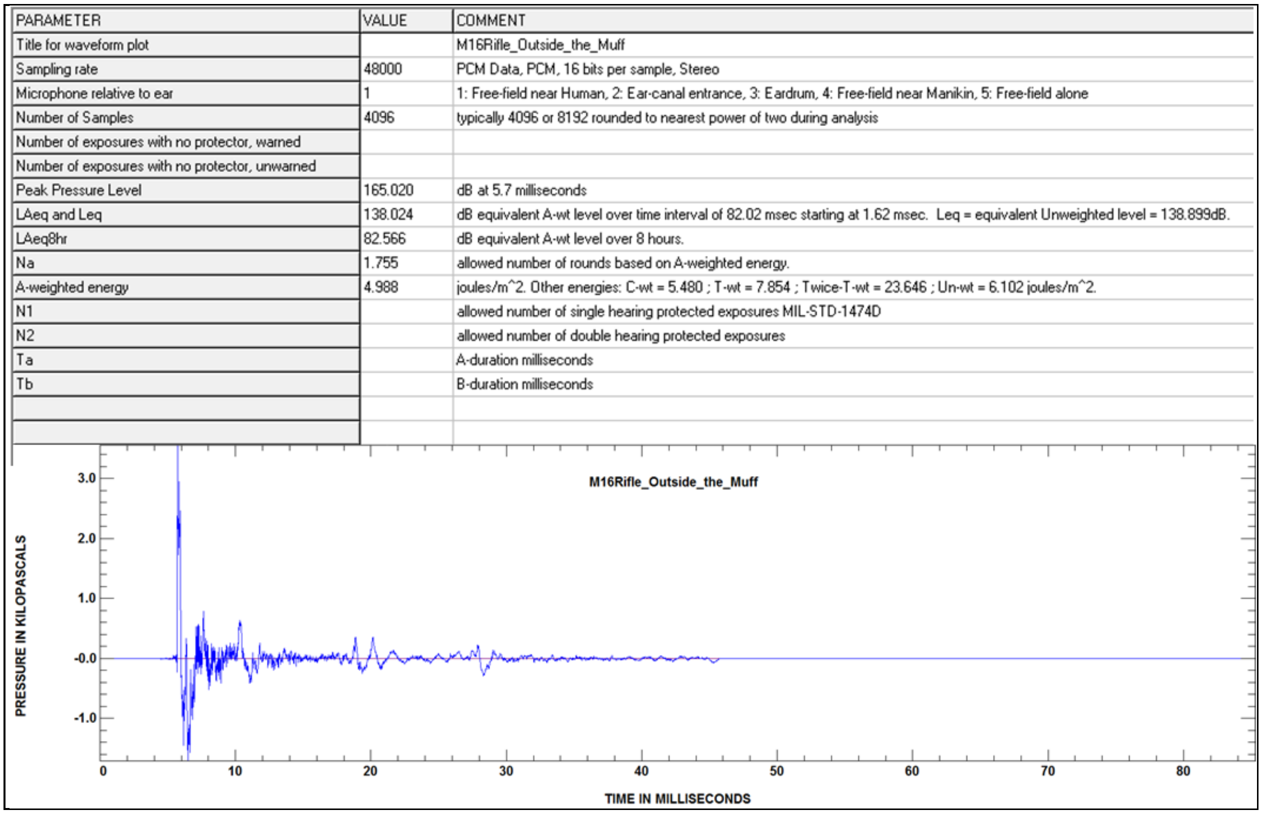
The *Statistics* command (section 2.6.4) can be used to verify that the peak pressure is now 165.020 dB. (The 0.020 dB is caused by using a six-digit rounded value of the multiplier.)

The location of this pressure waveform is outside the hearing protector ear muff; this is a free-field waveform measurement.

The *Microphone relative to ear location* can be left as *1 - Free-field*.

The screen will appear as shown in figure 19.

11. Select *File - Save AHA waveform as* and name the file M16Rifle_Outside_the_Muff



PARAMETER	VALUE	COMMENT
Title for waveform plot		M16Rifle_Outside_the_Muff
Sampling rate	48000	PCM Data, PCM, 16 bits per sample, Stereo
Microphone relative to ear	1	1: Free-field near Human, 2: Ear-canal entrance, 3: Eardrum, 4: Free-field near Manikin, 5: Free-field alone
Number of Samples	4096	typically 4096 or 8192 rounded to nearest power of two during analysis
Number of exposures with no protector, warned		
Number of exposures with no protector, unwarned		
Peak Pressure Level	165.020	dB at 5.7 milliseconds
LAeq and Leq	138.024	dB equivalent A-wt level over time interval of 82.02 msec starting at 1.62 msec. Leq = equivalent Unweighted level = 138.899dB.
LAeq8hr	82.566	dB equivalent A-wt level over 8 hours.
Na	1.755	allowed number of rounds based on A-weighted energy.
A-weighted energy	4.988	joules/m^2. Other energies: C-wt = 5.480 ; T-wt = 7.854 ; Twice-T-wt = 23.646 ; Un-wt = 6.102 joules/m^2.
N1		allowed number of single hearing protected exposures MIL-STD-1474D
N2		allowed number of double hearing protected exposures
Ta		A-duration milliseconds
Tb		B-duration milliseconds

Figure 19. M16Rifle.WAV right channel, outside the hearing protector muff.

The completed tutorial steps have demonstrated how to import waveforms, prepare them for AHAAH analyses, and save them as AHAAH input files of type AHA. In the next section, we will perform AHAAH auditory hazard analyses on the saved AHA input files and apply hearing protectors to AHA waveforms to analyze auditory risk when hearing protection is used.

3. Analyzing Waveforms for Auditory Risk Units

Once AHAAH has saved a waveform with an AHA file extension, the waveform can be reopened in AHAAH, and auditory risk analyses may be performed with the waveform. In this section, we show how to analyze waveforms to determine physical parameters of the waveform and how to perform auditory risk analyses.

The tutorial will continue with the use of the file TestImpulse.AHA, which is stored in the Data Files folder provided with the AHAAH model.

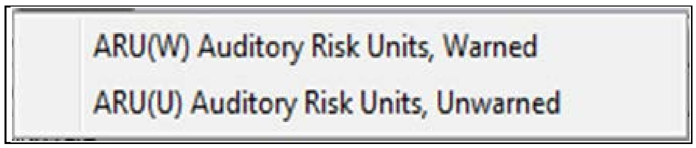
Tutorial goal: Open the TestImpulse. AHA file needed for analysis.

1. Select *File*, then *Open AHAAH Waveform*.
2. Navigate to and open TestImpulse.AHA.

You can perform a *Statistics* command to recalculate the physical parameters of the waveform.

3.1 Analyzing the Waveform for Auditory Hazard

After the AHA waveform has been opened, clicking on *Analyze* on the tool bar provides two analytical choices:



3.1.1 Selecting the Warning State

As discussed regarding the *Establish Start* command (section 2.6.5), the middle ear muscles can contract reflexively to intense sounds or, because they are connected to the central nervous system, they can contract for other reasons, such as in anticipation of an intense impulsive sound. AHAAH permits hazard analyses for conditions when the auditory reflex has been activated before the impulsive waveform arrives and for conditions when the auditory reflex is activated at some point during the impulsive waveform.

3.1.1.1 ARU(W) Auditory Risk Units, Warned

Muscles contracted prior to the impulse. The middle ear muscles may already be contracted when the impulse(s) being analyzed arrive. This can happen when there is some warning that an impulsive event is about to occur—for example, when Soldiers fire their own weapons. It can also occur when there is a precursor acoustic event not included in the waveform, like another impulse or high background noise. MIL-STD-1474E defines an exposure as a “warned” exposure when the person whose ears are exposed knows when to expect an impulsive noise (e.g., the person may be pulling the trigger or the next impulsive event is part of a series of events that are closely spaced, as in the firing of a machine gun). For these cases, a *Warned* condition should be selected.

Tutorial goal: Select the *ARU(W) Auditory Risk Units, Warned* analysis.

When *ARU(W) Auditory Risk Units, Warned* is selected, AHAAH performs the risk assessment and gives the result shown in figure 20.

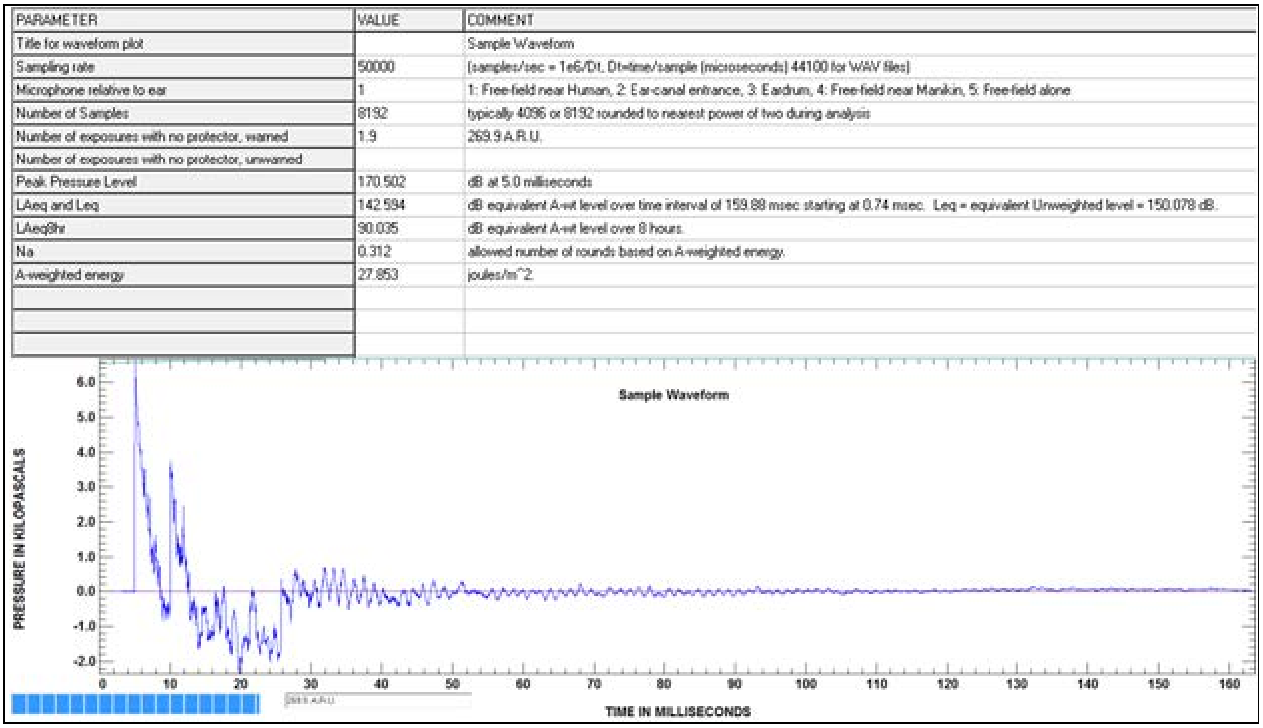


Figure 20. AHAAH screen results after analyzing ARU(W). Exposure to the *Sample Waveform* results in 269.9 ARU.

In addition to providing auditory risk results on the computer screen, AHAAH produces an ASCII file that presents a record of the risk analysis. The file is given the same file name as the AHA waveform file (in this case, TESTIMPULSE) and a file extension .HAZ. The file is written into the same directory as the AHA waveform file. In this case, the risk analysis file is named TESTIMPULSE.HAZ. The contents of TESTIMPULSE.HAZ can be viewed with any software that reads files with a .TXT file extension.

The HAZ file is written with values in columns separated by spaces. The HAZ file gives the auditory risk value associated with each 1/3 octave band frequency in the impulse. An example HAZ file is shown in section 5, “Software Output.” The risk value that AHAAH reports on screen is the largest ARU value that occurred in any of the 1/3 octave bands. For this TESTIMPULSE.AHA example, the reported overall risk value is 269.9 ARU.

If the HAZ file from an ARU analysis is to be retained and another ARU analysis is to be conducted with the same AHA file, you must rename or move the first HAZ file, or AHAAH will overwrite the HAZ file when a subsequent analysis is performed.

3.1.1.2 ARU(U) Auditory Risk Units, Unwarned

Muscles contract in response to the impulse. If it can be presumed that the person exposed was unaware that the impulse was coming, then an “unwarned” condition should be selected. AHAAH assumes that middle ear muscle contractions are triggered when the acoustic event

reaches 134 dB. At this point, a reflex latency of 9.2 ms begins in the model. After 9.2 ms, AHAAH begins to increase the modeled stiffness of the annular ligament element by a time constant of 11.9 ms until complete contraction (maximum stiffness) occurs, at which point complete contraction is held until the end of the analysis.

Tutorial goal: Select the *ARU(U) Auditory risk Units, Unwarned* analysis.

When *ARU(U) Auditory Risk Units, Unwarned* is selected after running the previous *ARU(W) Auditory Risk Units, Warned* analysis, AHAAH provides the cautionary note shown in figure 21.

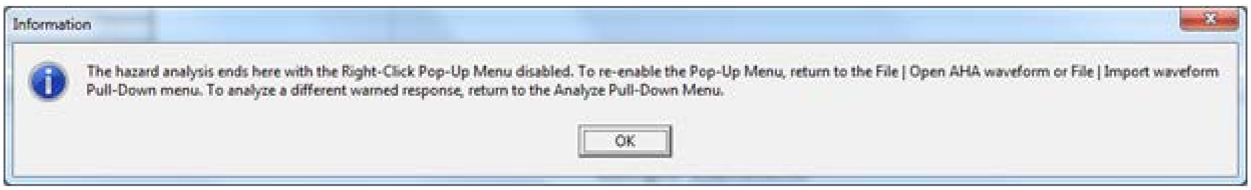


Figure 21. AHAAH warning note indicates that the right-click menu has been disabled, but further warned or unwarned analyses may be conducted.

This message box indicates that further waveform editing commands cannot be conducted unless the AHA waveform is reloaded into memory. This is because the waveform has been stored in memory with appended leading and/or trailing zero data values. Appending the waveform is necessary for performing the Fourier transforms and time-series analyses applied by AHAAH. To prevent the waveform from being appended multiple times, the right-click pop-up menu is disabled. However, since the waveform has been modified to perform auditory risk analyses, continued auditory risk analyses can be run. To repeat right-click pop-up menu commands, the AHA waveform can be reloaded.

After selecting *OK* in the warning message box, AHAAH runs the unwarned analysis and produces the screen result shown in figure 22.

PARAMETER	VALUE	COMMENT
Title for waveform plot		Sample Waveform
Sampling rate	50000	(samples/sec = 1e6/Dt, Dt=time/sample (microseconds)) 44100 for WAV files)
Microphone relative to ear	1	1: Free-field near Human, 2: Ear-canal entrance, 3: Eardrum, 4: Free-field near Manikin, 5: Free-field alone
Number of Samples	8192	typically 4096 or 8192 rounded to nearest power of two during analysis
Number of exposures with no protector, warned	1.9	269.9 A.R.U.
Number of exposures with no protector, unwarned	0.6	812.0 A.R.U.
Peak Pressure Level	170.502	dB at 5.0 milliseconds
LAeq and Leq	142.594	dB equivalent A-wt level over time interval of 159.88 msec starting at 0.74 msec. Leq = equivalent Unweighted level = 150.078 dB.
LAeq8hr	90.035	dB equivalent A-wt level over 8 hours.
Na	0.312	allowed number of rounds based on A-weighted energy.
A-weighted energy	27.853	joules/m^2.

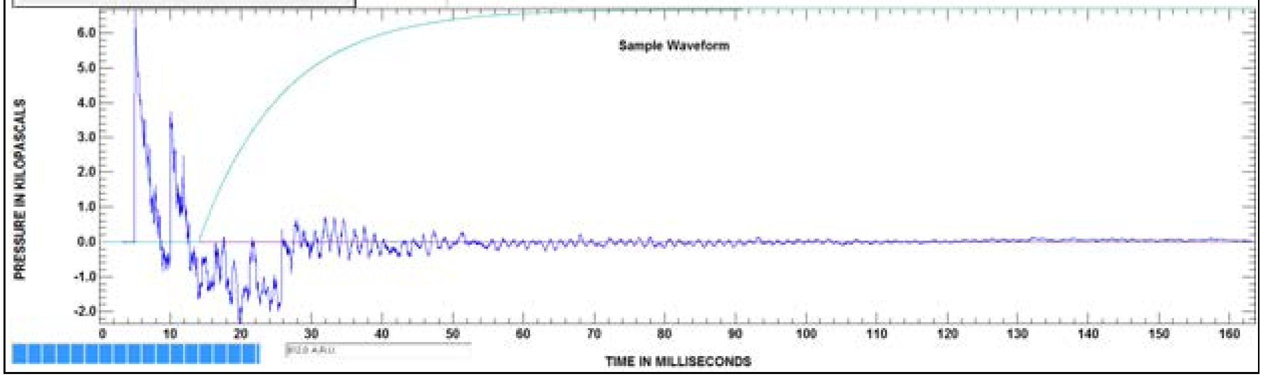


Figure 22. AHAAH screen results after analyzing ARU(U). Exposure to the *Sample Waveform* results in 812.0 ARU, which is the auditory risk for this impulse with no hearing protection and with no warning. (This image has been rescaled to improve legibility.)

Figure 22 shows that when the listener is unwarned, exposure to the *Sample Waveform* results in an auditory risk value of 812.0 ARU. This value may result in permanent hearing loss. The light blue line on the graph in this figure also shows the progressive onset of the auditory reflex, which was triggered at the rise of the initial pressure spike.

3.1.1.3 Analyses Summary

When the warned and unwarned analyses are run consecutively with the TESTIMPULSE.AHA file, the output screen shows the results in figure 23.

Since the *ARU(U) Auditory Risk Units, Unwarned* analysis was performed last, the HAZ file will reflect the *ARU(U) Auditory Risk Units, Unwarned* analysis, and the auditory risk value shown under the graph is 812.0 ARU, which is produced by the last AHAAH analysis. Unlike the auditory risk analyses commands, no file output is provided with the *Statistic* command.

As indicated in the earlier warning message box, after an auditory risk analysis is conducted, actions in the AHAAH right-click pop-up menu are disabled. To further process or analyze the waveform, the AHA file must be reopened. We will do this in section 3.2.4, which deals with applying hearing protection.

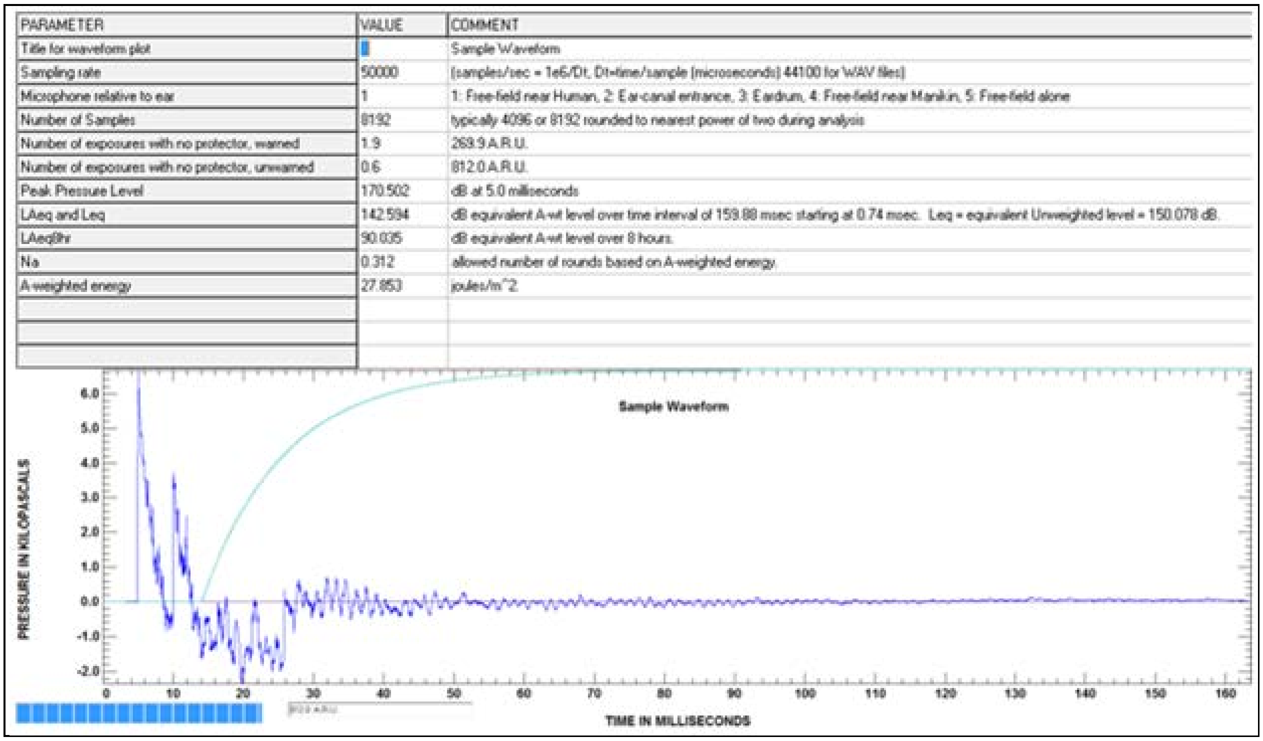


Figure 23. AHAAH screen results after performing the *ARU(W) Auditory Risk Units, Warned* analysis and the *ARU(U) Auditory Risk Units, Unwarned* analysis. (Image has been resized for legibility.)

3.2 Considerations in the Use and Interpretation of the Results

3.2.1 ARUs

The output of the program is ARUs, which have a specific physical definition inside the cochlea. The quantified auditory risk assessment is performed at 23 evenly spaced locations along the basilar membrane. The location with the largest value has the highest probability of incurring hearing damage from exposure to the impulsive sound, and the number of ARUs at that location is reported as an overall summary of the auditory risk associated with exposure to the impulsive waveform. MIL-STD-1474E prescribes auditory risk acceptance criteria such that the limit of impulsive noise exposure for occasional (no more than once per week) occurrence within any 24-h sliding window period shall not exceed 500 ARUs as calculated by AHAAH. For occupational exposures that happen two or more times per week, the limit shall not exceed 200 ARUs per 24-h sliding window period. Exceeding these limits may result in noise-induced hearing loss.

This prescription is based on the direct relation between ARUs, temporary changes in hearing sensitivity, and the probability of permanent hearing loss. A dose of 500 ARUs is barely safe, meaning that there may be temporary shifts in hearing sensitivity of up to 25 dB, but recovery should occur within 24 h, and no permanent hearing loss is expected from the exposure. A dose of 200 ARUs is more reasonable as an occupational dose limit where daily or near daily exposures could occur, as reflected in the MIL-STD-1474E.

3.2.2 Multiple Exposures

The ARUs from separate impulses should be summed to arrive at the total dose within a 24-h period. One large impulse with 400 ARUs is equivalent to four impulses with 100 ARUs or 100 impulses with four ARUs, and so forth. If an individual impulsive event produces a hazard rating of 10 ARUs, the maximum number of impulses permitted per day for occasional exposure is 50 events in a 24-h period (500 ARU/24 h divided by 10 ARU/event). If multiple exposures approaching tolerable limits are likely, monitoring audiometry at frequent intervals is strongly recommended.

3.2.3 Proportion of the Population Protected

The AHAAH model predicts auditory hazard for the 95th percentile ear (most susceptible ear).

3.2.4 Selecting Hearing Protection

3.2.4.1 Overview of Hearing Protection Application

The MIL-STD-1474E version of AHAAH contains data sets allowing the user to analyze auditory risk with an extensive set of hearing protectors. A table describing AHAAH's default hearing protectors is given in appendix B. Appendix B also contains a nominal list of hearing protectors currently available in AHAAH.

Hearing protector performance is based on attenuations measured in seven octave bands at frequencies from 0.125 to 8.0 kHz. (Some protectors include eight octave band measurements, starting at 0.0625 kHz.) The protector configurations are described in MIL-STD-1474E.

Using the measured attenuation values, AHAAH obtains the physical parameters for a multi-piston-leak acoustical engineering model of the protector. AHAAH then applies the protector's acoustical engineering model to determine waveform spectral attenuations, resonances, and phase shifts for the dynamic temporal transfer of the waveform across the hearing protector.

AHAAH calculates the pressure-time history under the hearing protector. The default location for the calculated waveform under the hearing protector is at the eardrum. In section 2.5, "Specifying Microphone Location," the entrance to the ear canal is shown to be location 2, while the eardrum location is shown to be location 3. AHAAH also will alternately calculate the pressure time waveform at the entrance to the ear canal. This can be useful if waveform measurements are available at the ear-canal entrance. The user can change the location after a hearing protection configuration is selected. This option allows the user to calculate pressure-time waveforms at different locations for comparison with experimentally measured waveforms.

AHAAH also allows the user to select the angle from which the sound is incident on the head. The default for the AHAAH risk assessment is sound incident along the interaural axis, from an angle of 90° from the facing direction. This angle produces a severe exposure to the ear facing the incident sound. However, when hearing protection is applied, the incidence angle can be

changed to consider grazing incidence from the front (0°), grazing incidence from the back (180°), fully head-shadowed incidence (270°), or any angle selected between 0° and 359°. By adjusting this angle, AHAAH calculates the appropriate pressure time history for incidence from the specified angle relative to the facing direction. Although the incidence angle can be adjusted, AHAAH still applies symmetry azimuthally around the interaural axis, so that incidence from 45° and 135° will yield the same results.

After calculating the waveform at the eardrum, AHAAH automatically saves the waveform and the updated waveform location as an AHA file with an updated file name. The updated file name consists of the filename of the original waveform followed by the name of the hearing protection configuration and the selected angle of incidence. AHAAH overlays the under-the-protector waveform in the screen's waveform panel, allowing a visual comparison with the incident waveform.

To complete the hearing protection analysis, the user must open this new AHA file and select the desired analysis. The microphone location specified in the new file now reflects the selected location under the hearing protector.

3.2.4.2 Applying Hearing Protection to a Waveform

AHAAH allows you to determine the hazard of an impulsive noise exposure when the exposed individual is using hearing protection. This capability represents a significant step forward in quantitative hazard assessment. In the hearing protection module, you have the option to choose *DEFAULT MODE*, which permits you to select one of a number of hearing protection configurations considered to be "standard" for various military applications.

If you are interested in the effect of a specific hearing protection device or combination of devices, AHAAH offers scores of devices available under the *POWER USER MODE* instead of the *DEFAULT* mode. The available devices include most known plugs and muffs used by, or considered for use by, the U.S. military.

To apply hearing protection, you must select an appropriate hearing protector to apply to the free-field waveform. The following tutorial leads you through applying hearing protectors in AHAAH.

Tutorial goal: Analyze the hazard of the TestImpulse.AHA impulse with a hearing protector.

1. Restart AHAAH and open the TESTIMPULSE.AHA waveform.
2. From the right-click drop-down menu, select *APPLY HEARING PROTECTION - POWER USER MODE - MUFF - LEVEL INDEPENDENT - PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES*. (The menu progression is shown in figures 24–26.)

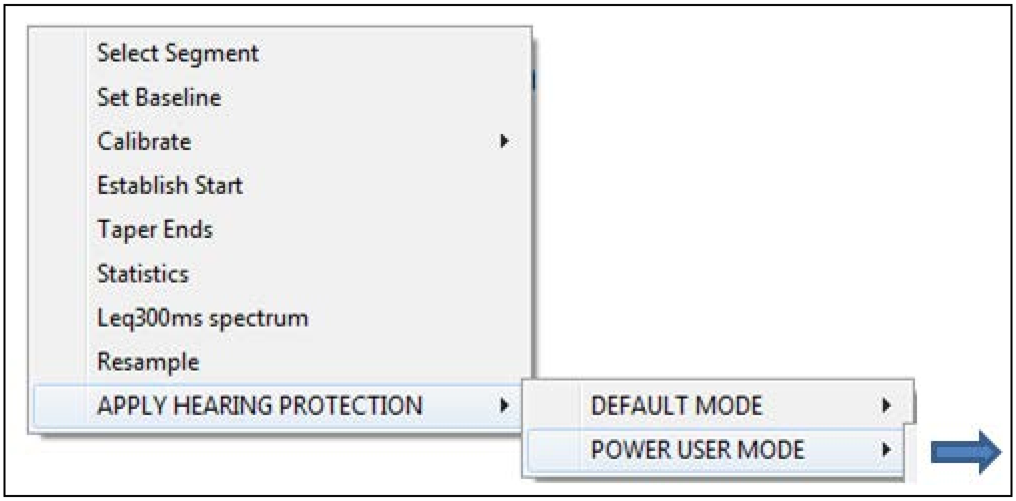


Figure 24. The right-click drop-down menu, the selection of *APPLY HEARING PROTECTION*, and the choice of *DEFAULT MODE* or *POWER USER MODE*.

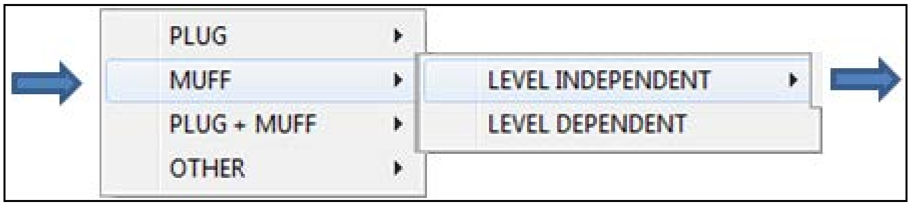


Figure 25. Selecting a *MUFF* hearing protector.

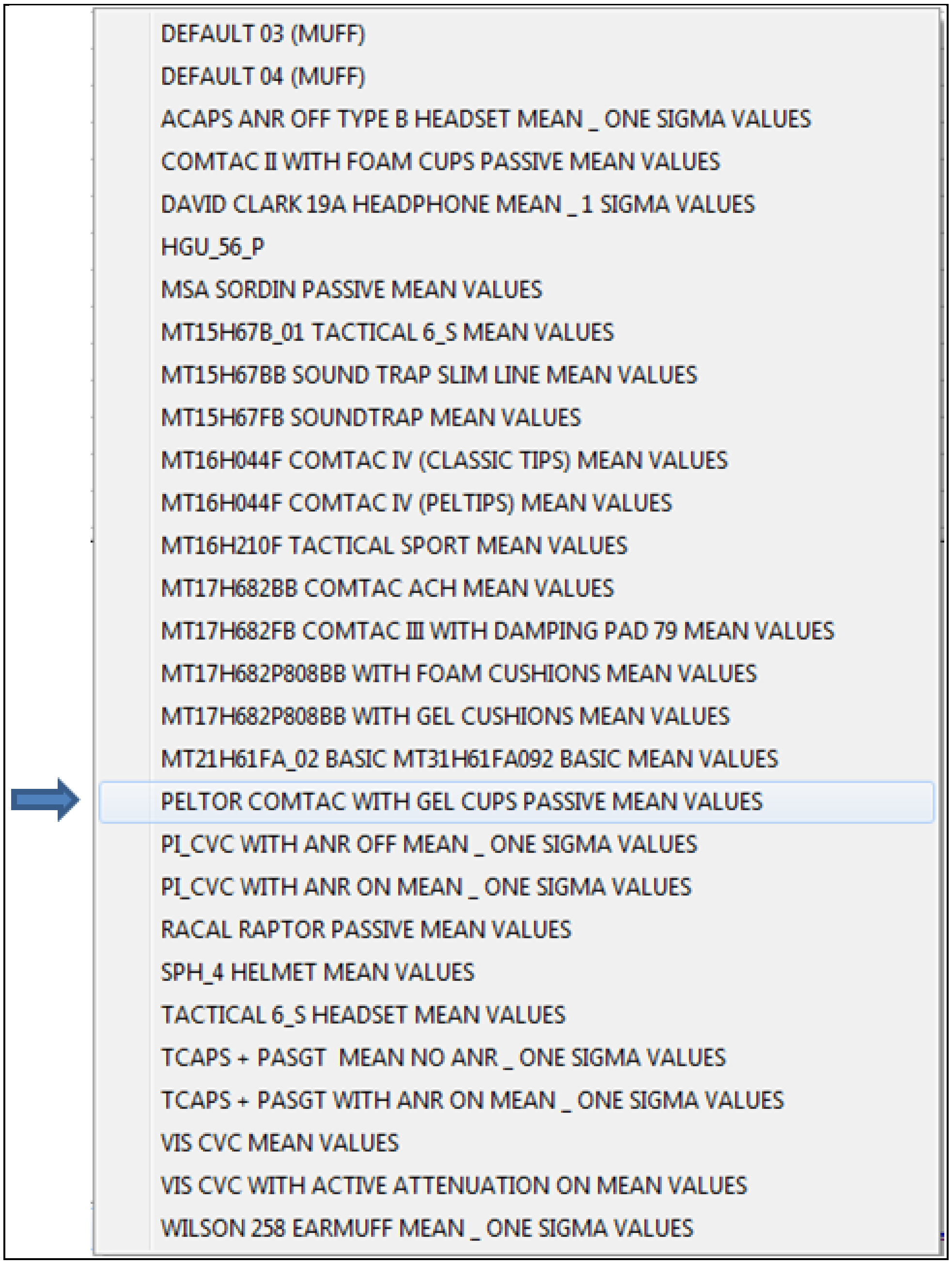


Figure 26. Selecting the *PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES*.

When this hearing protection is selected, AHAAH will tell you that the default location for the waveform prediction under this muff is at the eardrum and ask if you want to accept this default. The information and question are shown in figure 27.

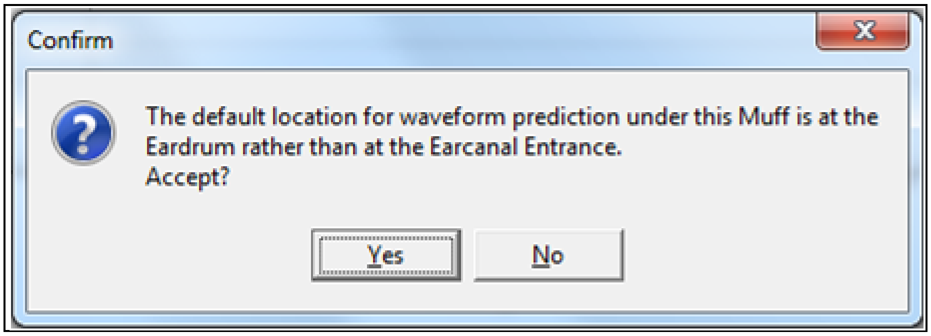


Figure 27. Text box confirming the location for waveform prediction under the hearing protector.

Tutorial goal: Accept the default location for the waveform prediction. Select *Yes*.

If the default location (the eardrum - location 3) is not accepted, AHAAH will calculate the pressure under the hearing protector at the entrance to the ear canal (the ear canal entrance - location 2). With an ear plug, this location is just past the inner surface of the ear plug. Using the location option, you can estimate the waveform at either the eardrum or just inside the hearing protector. This facilitates comparisons between hearing protectors implemented in AHAAH and experimental measurements made with microphones appropriately placed beneath hearing protectors.

Next, AHAAH asks for a specification of the direction from which the sound is incident. AHAAH indicates that the default angle of the incoming wave at this hearing protector, relative to the facing direction, is 90° for normal incidence rather than 270° for head-shadowed incidence or 0° for grazing incidence. AHAAH asks if 90° incidence is acceptable. The text box is shown in figure 28.

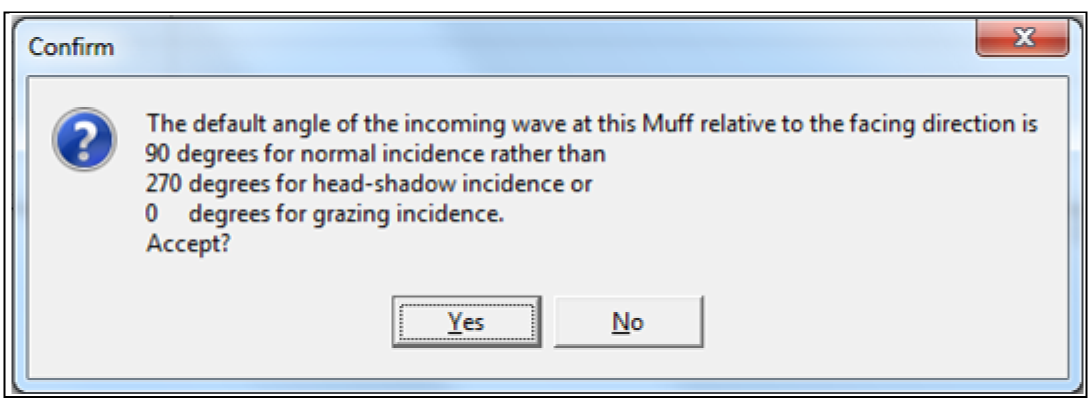


Figure 28. Text box for the default angle of sound incidence.

Tutorial goal: Reject the default angle of the incoming wave at this muff relative to the facing direction. Select *No*.

When *No* is selected, AHAAH asks you to type in an integer angle (0°–360°), with the text box shown in figure 29.

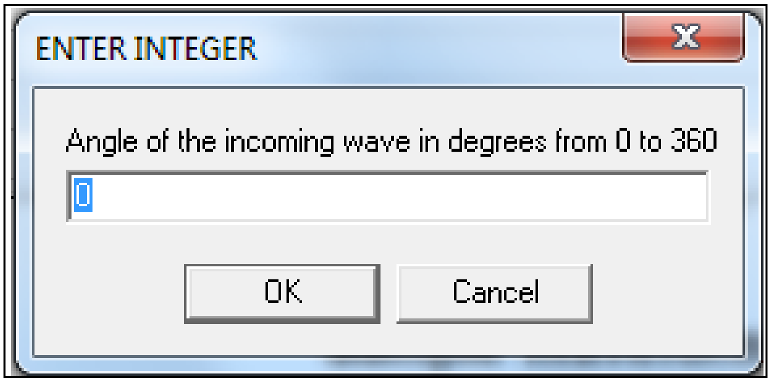


Figure 29. Text box for input of sound incidence angle as an integer from 0° to 359°.

Entering 360° is accepted, but the results of the calculation will be the same as if 0° was entered.

Tutorial goal: Type in 90° (restoring the default value of the angle of the incoming wave at this muff relative to the facing direction, but demonstrating the process of changing the angle). Select *OK*.

Once the sound incidence angle is specified, AHAAH analyzes the pressure-wave transfer through the hearing protector and calculates the pressure-time waveform at the location specified under the hearing protector. The calculation results are shown in figure 30.

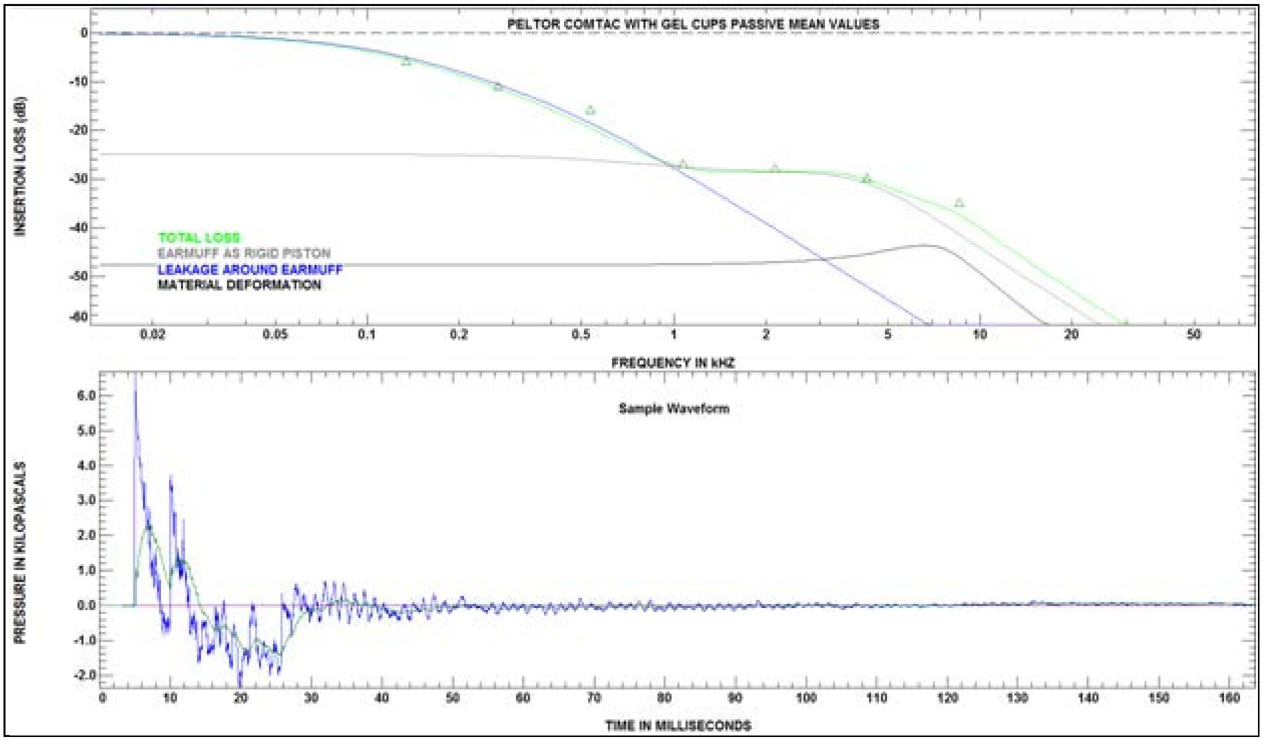


Figure 30. AHAAH results for TestImpluse with the *PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES* hearing protector. The waveform in green is the pressure-time waveform at the eardrum - location 3.

When sound transmission through a hearing protector is analyzed, AHAAH displays in the upper screen the attenuation measurements that are the basis of the hearing protector's performance. This attenuation is shown as a function of frequency. AHAAH refers to the upper portion of the screen as the *SPECTRUM*. AHAAH shows the spectrum of *TOTAL LOSS* (green line) provided by AHAAH's model of the protector, and the attenuation characteristics of the individual components of the engineering electroacoustic hearing protector model, including attenuation spectrum due to the hearing protector (muff, or plug, or combined muff and plug) behavior as a single rigid acoustical engineering piston (*EARMUFF AS RIGID PISTON* - gray line), the leakage spectrum around the hearing protector (*LEAKAGE AROUND EARMUFF* - blue line), and attenuation spectrum for sound transmission through the combined hearing protector (*MATERIAL DEFORMATION* - black line).

In the lower section of the screen, called the waveform section, AHAAH graphs the original pressure-time waveform (blue line) and the resulting pressure-time waveform under the hearing protector (green line).

These regions of the screen can be copied to the clipboard and inserted into other documents to create a record of the hearing protector analysis (see section 3.2.5.2 for AHAAH's *Copy* Command).

After calculating the waveform at the eardrum, AHAAH automatically saves the waveform under the hearing protector, along with the header information, including the location of the waveform (*MICROPHONE RELATIVE TO THE EAR*), which is normally location 3, as an AHA file with an updated file name. The updated file name consists of the file name of the original waveform followed by the name of the hearing protection configuration and the selected angle of incidence. If 360° was entered as the incidence angle, the file name will include the value, 360, but the file results will be the same as if an angle of 0° (zero) was entered. In this tutorial case, the name of the automatically saved AHAAH file (.AHA file type) is:

Testimpulse_PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES_90.AHA

This file is saved in the same directory containing the waveform file that was originally opened in AHAAH.

Caution: To continue with the hearing risk analysis, do not go directly to the *ANALYZE* option and choose a warned or unwarned analysis. AHAAH has updated the location *MICROPHONE RELATIVE TO EAR* in its data, but it still holds the original waveform, TestImpulse, in its active waveform buffer. TestImpulse is a free-field waveform. An accurate hearing risk analysis will not be obtained if a free-field waveform is analyzed as though its location was at the eardrum.

To continue with AHAAH analyses of the auditory risk posed by the TestImpulse waveform with the *PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES* hearing protector, it is necessary to open the file just saved. You do not need to exit AHAAH, but to continue the analysis, you must open the file that was automatically saved:

Testimpulse_PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES_90.AHA

Tutorial goal: Open the just-saved impulse file for auditory risk with the selected hearing protector.

1. Click AHAAH's *File* drop-down menu.
2. Select *Open AHA waveform*.
3. Select the file:

Testimpulse_PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES_90.AHA

4. Click *Open*.

Note that the *MICROPHONE RELATIVE TO EAR* location is now shown as location 3 - eardrum.

Tutorial goal: Analyze the unwarned auditory risk associated with using the selected hearing protector.

1. Click AHAAH’s *Analyze* drop-down menu.
2. Select *ARU(U) Auditory Risk Units, Unwarned*.
3. Notice that the auditory risk is 15.5 ARU.

As described in section 3.2.1.1, “ARU(W) Auditory Risk Units, Warned,” after performing this analysis, AHAAH saves the resulting ARU values in a HAZ file, which AHAAH saves in the same directory as the AHA waveform file.

Tutorial goal: Analyze the warned auditory risk associated with using the selected hearing protector.

1. Click AHAAH’s *Analyze* drop-down menu.
2. Select *ARU(W) Auditory Risk Units, Warned*.
3. Notice that the auditory risk is 2.19 ARU.

Unless you renamed the HAZ file saved after the previous unwarned analysis, AHAAH has overwritten the unwarned HAZ file, replacing it with the warned HAZ file. As described earlier, if you need to save a particular HAZ file and you must perform multiple analyses with the same AHA file, you must rename the HAZ file after each analysis.

For this tutorial, overwriting the unwarned analysis HAZ file is acceptable because you now know how to run complete analyses using waveforms, hearing protectors, and warned and unwarned conditions, and you can easily repeat the warned or unwarned analysis.

3.2.5 Additional Waveform Functions

In addition to auditory risk analysis for waveforms, AHAAH can perform spectral analyses of waveforms and compare the spectra of different waveforms that have been saved as AHA files. AHAAH also allows you to copy screen images to the computer clipboard. You can copy the waveform portion of the screen, the spectrum portion of the screen (or the header area, if the header is displayed), or the entire active screen. These commands are described in the following sections.

3.2.5.1 The *Leq300ms spectrum* Command

AHAAH can calculate the spectrum of a waveform using the *Leq300ms spectrum* command on the AHAAH right-click pop-up menu shown in figure 31.

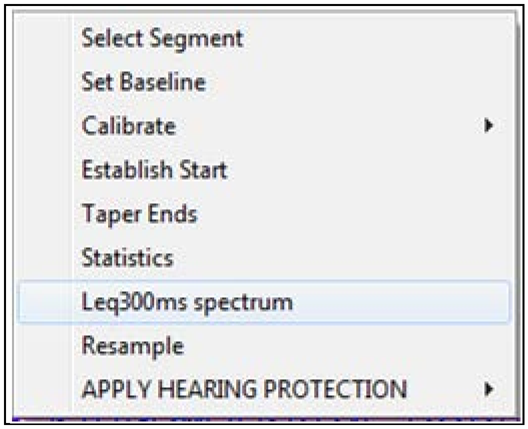


Figure 31. The *Leq300ms spectrum* command in the AHAAH right-click pop-up menu.

AHAAH has also saved the third-octave band (TOB) results in an ASCII file with space-separated values. The TOB file is given the same name as the AHA file, but the file extension has been changed to TOB.

Tutorial goal: Calculate and display the spectrum and the TOB levels of the TestImpulse.AHA waveform.

1. Open the file TestImpulse.AHA.
2. From the AHAAH right-click pop-up menu, select the command *Leq300ms spectrum*.

The spectrum of the waveform is shown in the upper portion of the screen (blue line). Also shown are the TOB energy levels (green line) of the waveform. The TOB levels show the amount of energy the waveform has in one-third octave intervals at specific frequencies. The energies are represented as the equivalent of a sinusoidal wave at the central frequency of the band, lasting for 300 ms. TOB 300-ms spectra are frequently used to characterize the audibility of sounds. After performing the *Leq300ms spectrum* command, the screen appears as shown in figure 32.

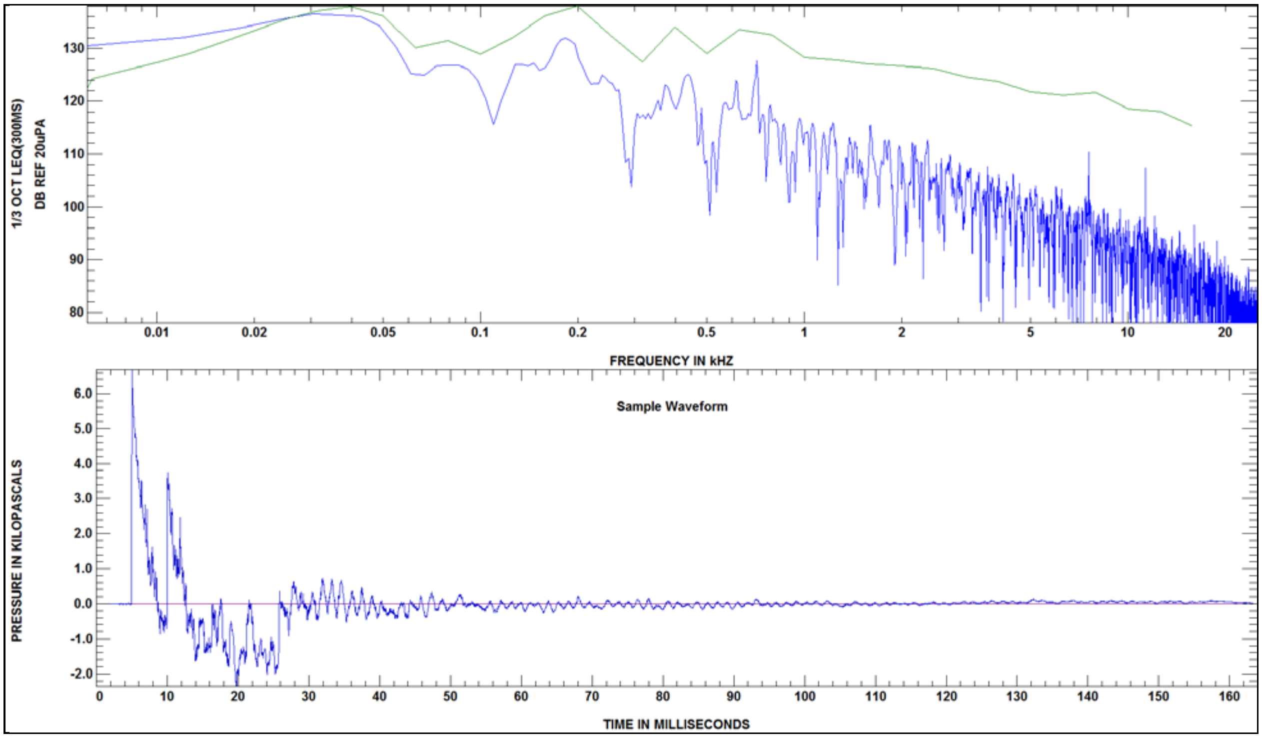


Figure 32. The AHA file TestImpulse.AHA and its spectrum (blue line) and TOB (green line).

As previously indicated in regard to disabling the right-click pop-up menu, in calculating the waveform spectrum and its TOB values, AHAAH applies fast Fourier transform processes to the waveform. These processes require the waveform to be appended with zero pressure fluctuation values to prevent aliasing in the frequency representation. Because the waveform has been appended in the computer memory, it is not possible to accurately perform subsequent right-click pop-up menu analyses. Thus, to continue such analysis of the AHA file waveform, the AHA file must be reopened. To prevent inaccurate analyses from being performed, the AHAAH right-click pop-up menu is disabled, and a warning window is displayed after performing the *Leq300ms spectrum* command. The displayed window is shown again in figure 33.

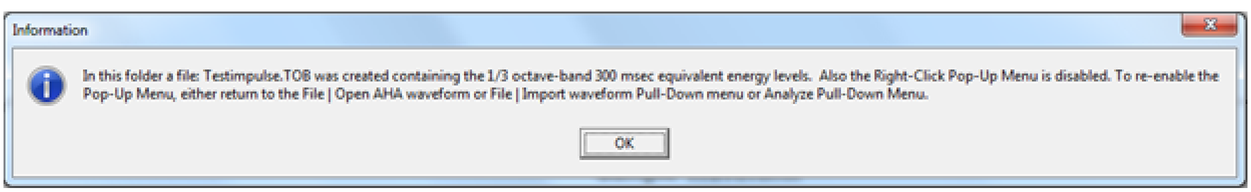


Figure 33. AHAAH announcement to reopen a file for continued analyses.

When this window appears, click *OK* and proceed to perform continued auditory risk analyses with the waveform in memory, or reopen the AHA file to perform further right-click pop-up menu waveform processing.

3.2.5.2 The Overlay AHA Waveform Command

We will restart AHAAH and show how different AHAAH waveforms can be compared.

Tutorial goal: Perform AHA waveform comparison.

1. Close AHAAH.
2. Rename the AHA hearing protector waveform file produced in section 3.2.5.2 as follows:

   Original file name:

   Testimpulse_PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES_90.AHA

   New file name:

   Testimpulse_PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES_90-L3.AHA

This will allow the user to apply the same hearing protector to the same impulse waveform without overwriting the previously saved AHA hearing protector waveform.

3. Restart AHAAH.
4. Open the AHA file TestImpulse.AHA.

As was done in section 3.2.5.2,

5. Select *APPLY HEARING PROTECTION - POWER USER MODE - MUFF - LEVEL INDEPENDENT - PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES*
6. Reject the default location for the calculated waveform. This changes the location from the eardrum (location 3) to the ear canal (location 2).
7. Accept *Default angle of the incoming wave at this Muff relative to the facing direction*. AHAAH calculates the waveform under the hearing protector at the location of the ear canal and saves the waveform as an AHA file with the following name:

   Testimpulse_PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES_90.AHA
8. Open the just-saved AHA file:

   Testimpulse_PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES_90.AHA

   (This AHA waveform is calculated at the ear canal, location 2.)
9. From the *File* drop-down menu, select *Overlay AHA Waveform*.
10. Select the following file name:

    Testimpulse_PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES_90-L3.AHA

Observe the screen results.

The comparison of these two AHA waveforms is shown in figure 34.

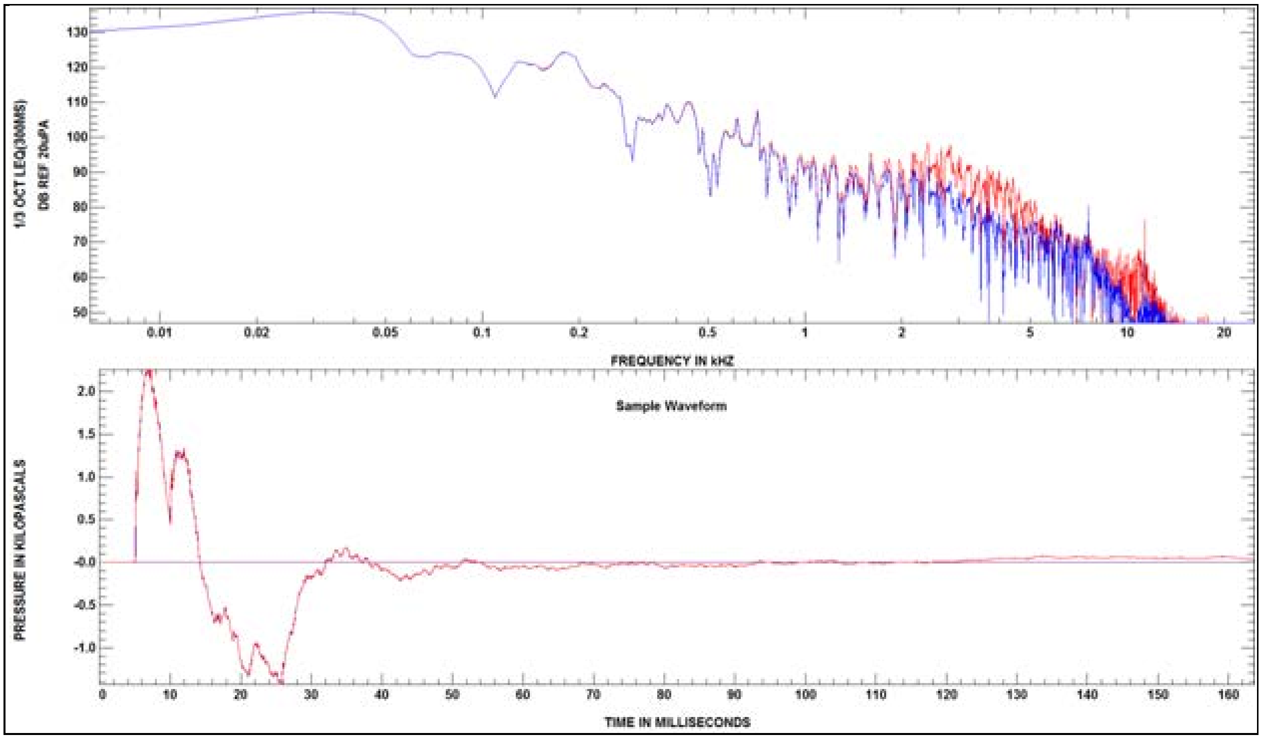


Figure 34. Comparison of AHA under-the-protector waveforms at the ear canal (blue line) and at the ear drum (red line).

The waveforms shown in the lower half of figure 34 look very similar. The difference between these two waveforms is apparent by comparing their spectra, which are shown in the upper part of the screen. The waveform at the eardrum (red line) reflects the 4-kHz resonance expected in sound propagation through the ear canal.

3.2.5.3 The Copy Command

AHAAH also provides copy commands, allowing the user to capture portions of the AHAAH screen output for analysis records or for inserting into reports. To copy AHAAH screen results, the AHAAH drop-down file menu provides three copy commands. The first copy command, *Copy screen to clipboard* (highlighted in figure 35), copies the entire AHAAH output screen to the Windows clipboard.

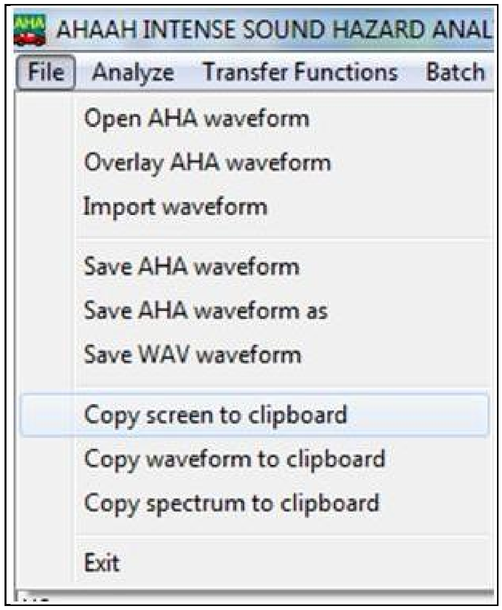


Figure 35. AHAAH drop-down *File* menu.

The second copy command, *Copy waveform to clipboard*, copies only the lower graph portion of the screen to the clipboard, while the third copy command, *Copy spectrum to clipboard*, copies the upper portion of the screen to the clipboard. As shown earlier in figure 18, this screen portion displays spectra when *Overlay AHA waveform* has been selected. When no spectrum is displayed, the *Copy spectrum to clipboard* command copies an image of the numerical results header, such as the one shown earlier in figure 22 and various previous figures.

This completes the description of all the commands in the *File* drop-down menu.

4. The Movie: An Interpretive Tool

In calculating the effect of an impulse on the ear, the model computes the behavior of the basilar membrane at 23 locations during the impulse duration. By reassembling this information and playing it back sequentially, it is possible to create a "movie" of the effect of the impulse. By comparing the movements of the basilar membrane to the instantaneous acoustic events, the user can gain insight into what parts of the waveform are responsible for the accumulated hazard.

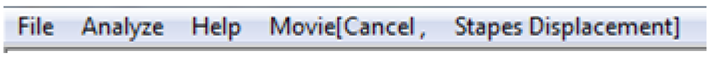
(Note: When performing multiple hearing risk analyses, the movie that will be shown is for the most recent analysis run.)

4.1 Viewing the Movie

Tutorial goal: Observe the hearing risk analysis "movie".

1. Open the AHA file: TestImpluse.AHA.
2. Click AHAAH's *Analyze* drop-down menu.
3. Select *ARU(U) Auditory Risk Units, Unwarned*.

Once the hazard has been calculated, a new AHAAH menu bar appears:



The selection *Stapes Displacement* will create a plot showing the movement of the stapes during the acoustic event and will show the progression of the contraction of the middle ear muscles.

Tutorial goal: Plot the stapes displacement for the current analysis (*No protector*, *Unwarned*).
· Click on *Stapes Displacement* within the *Movie* selections and there will appear a new screen as shown in figure 36.

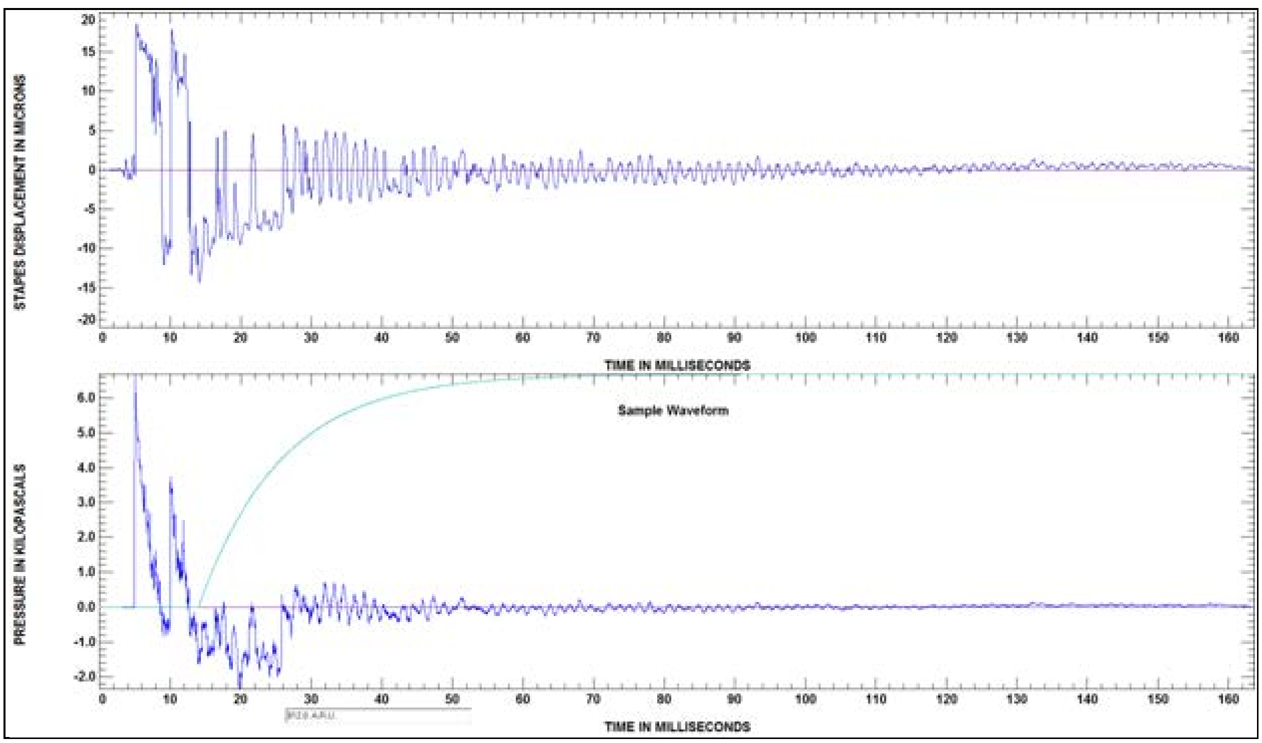


Figure 36. Stapes displacement screen (*No protector, Unwarned*) for TestImpulse.AHA.

The top graph shows the predicted stapes displacement during the impulse. The stapes displacement is given in microns. The lower plot is the waveform just analyzed with the middle ear muscle contraction curve superimposed on it in cyan. (The contraction curve goes from zero to 100% effect.)

After the stapes displacement is calculated, a new menu bar appears:

Tutorial goal: Prepare to view the movie.

・ Click on *Unwrap Cochlea*. The screen now appears as shown in figure 37.

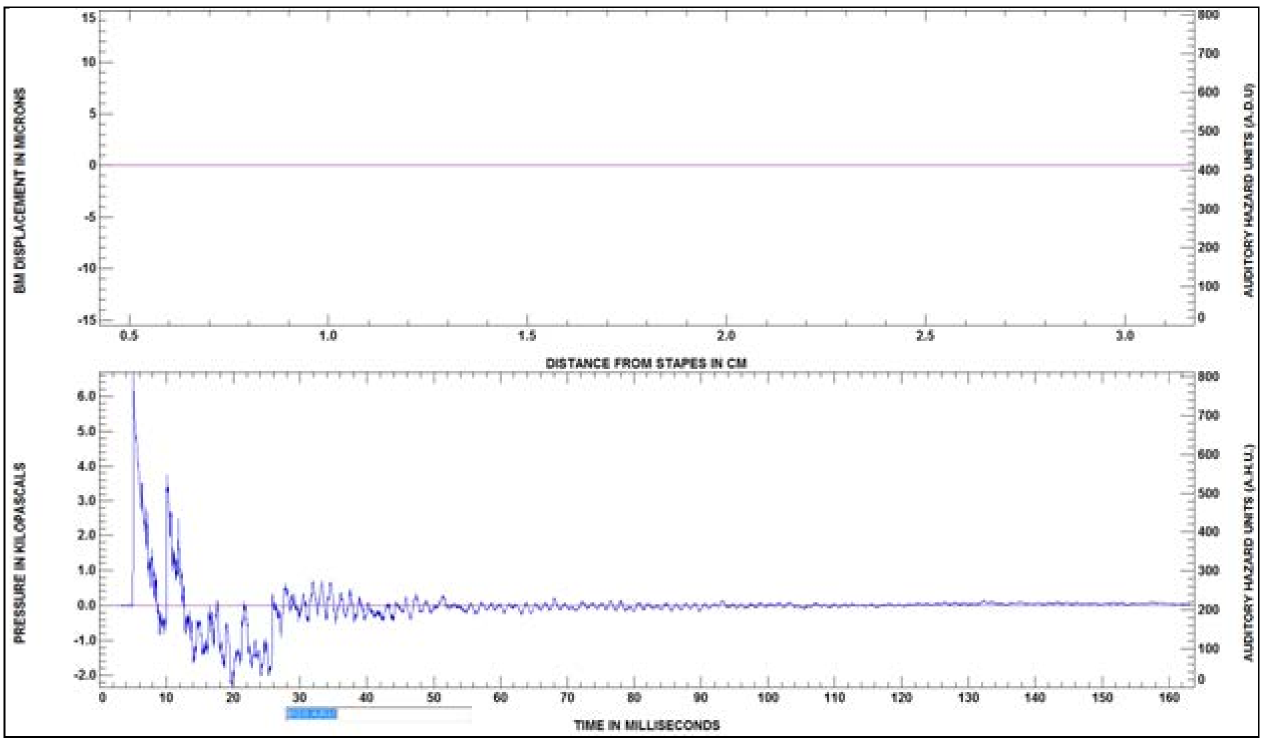
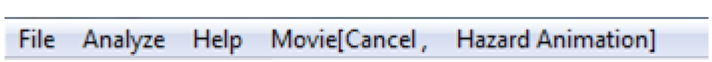


Figure 37. Unwrapped cochlea screen (*No protector, Unwarned*) for TestImpulse.AHA.

The top plot has become the unrolled cochlea, basal end to the left, apex to the right. The line in the middle is the basilar membrane, with the scala vestibuli (driven by the stapes) above and the scala tympani below. The menu bar now contains a new option.



Tutorial goal: View the movie.
· Click on *Hazard Animation*.

In the lower pane, the plot of the waveform changes color (from blue to green) as the analysis progresses through the pressure history. Also, as the analysis progresses, a new line (in red) is created, which represents the summed risk (in ARUs) at that point in the waveform. A sharp rise in this line indicates that risk has accumulated rapidly at that point. This line also is scaled to end at the top of the panel, which represents reaching 100% of the total calculated risk, independent of the magnitude of the risk.

In the upper plot panel, the green line is a plot of the instantaneous deflection of the basilar membrane, with the distance from the stapes increasing from left to right, as shown on the scale at the bottom. The outer blue lines represent the envelope of the history of basilar membrane movement from the beginning of the analysis to that point in time. In other words, all movements of the basilar membrane to this point in time can be enclosed by the blue lines. The deflection magnitude scale is on the left. The red line, which grows during the analysis, is the accumulated risk in ARUs mapped against where the risk has occurred on the basilar membrane. As in other graphs of the risk, this line is scaled so that the top of the plot is 100% of the accumulated risk, regardless of the magnitude of the risk. The ARU scale is on the right.

4.2 Interpreting the Movie: An Example

Figure 38 is a snapshot of the TestImpulse.AHA Unwarned Auditory Risk analysis movie.

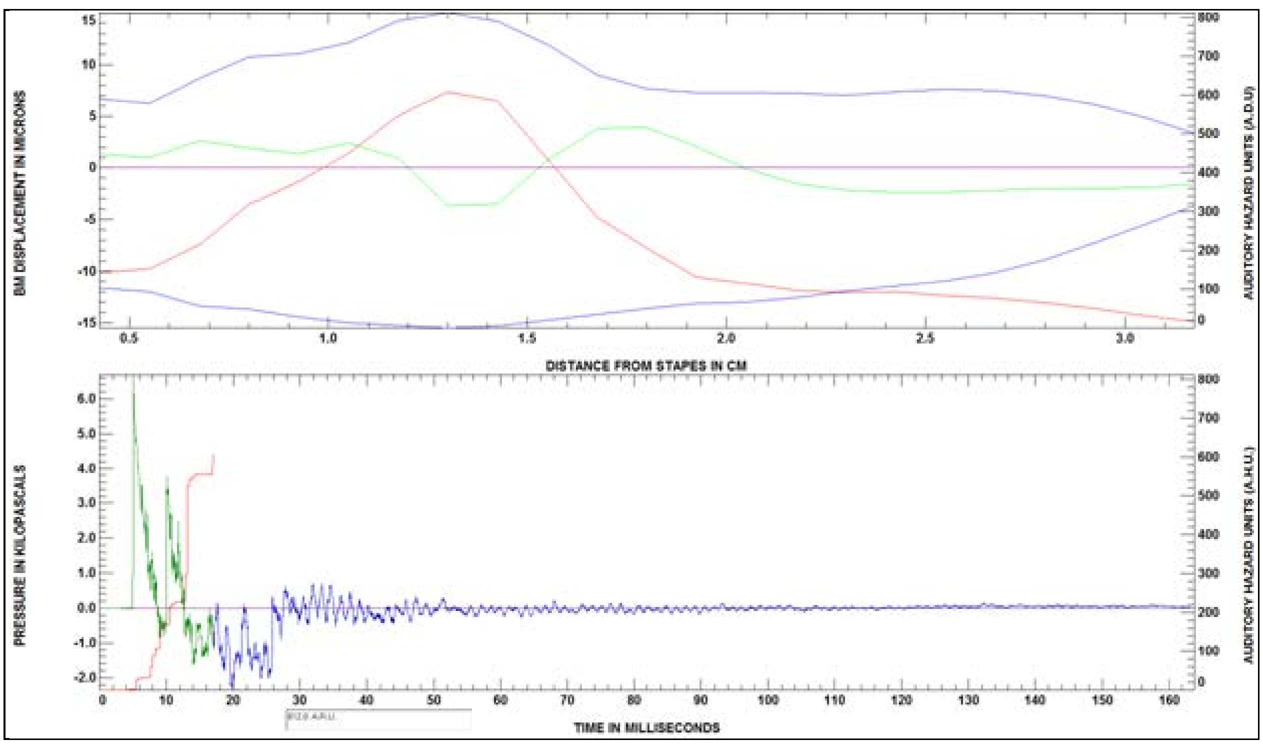


Figure 38. Movie of TestImpulse.AHA unwarned analysis paused.

The total auditory risk calculated for this exposure is 812 ARU. This is reflected in three places: in the ARU window near the bottom of the lower pane, by the maximum value of the right side scale of the lower pane, and by the maximum value of the right side scale of the upper pane. The accumulated auditory risk at this moment is about 600 ARU, shown by the red lines in both panes and read on the right scales. In the top pane, the physical location on the basilar membrane at which this value of hazard (640 ARUs) is being experienced is about 1.3 cm in from the stapes, read on the bottom scale. Note that the overall risk reported in the AHAAH analysis is the maximum risk experienced at any point along the basilar membrane.

The analysis is currently at about 18 ms into the waveform, shown by the extent of the waveform, which has changed from blue to green in the bottom pane, with the time scale along the bottom of the lower pane. In the top pane, at about 1.3 cm from the stapes (bottom scale), the basilar membrane will reach the maximum deflection in both the direction of the scala vestibuli and the scala tympani during the analysis (the blue lines at this distance show that this location will reach the top and bottom of the total movement scale). In the top pane, the current instantaneous deflection of the basilar membrane is about 4 µm in the direction of the scala vestibuli (left scale) at 1.7 cm from the stapes (bottom scale).

In the bottom pane, note that when the first positive peak passed at about 8 ms into the analysis, the hazard curve in the bottom panel had reached only about one-fifth of the total number of ARUs that will accumulate. This first peak contains about half of the total energy of the impulsive event, and it is this first peak upon which traditional analysis has tended to focus. However, the hazard at this point is manageable, and from an engineering standpoint, focusing on making the remaining part of the waveform safer would be good idea. The hazard accumulation line in the bottom panel further shows that for this particular impulse, about half the dose occurs when the second peak returns to atmospheric pressure. This feature of the model provides a powerful tool for engineering insight.

4.3 Keyboard Movie Controls

Certain keys on your keyboard can control the action of the movie. These keys are:

"Alt"	Freezes the animation so that you may examine the instantaneous plot in more detail; press again to resume the animation.
Up arrow	Increases animation speed (repeat to increase speed).
Down arrow	Slows animation speed (repeat to decrease speed).
"Home"	Restarts animation from beginning.

Once the movie has reached completion, in order to see it again you must reload the waveform, analyze the risk, and start the animation again.

The Movie [cancel] selection cancels playback of the movie and returns you to the AHAAH waveform window.

As indicated before, after displaying the hazard animation movie, the waveform must be reopened to continue further analyses on the right-click pop-up menu. The message announcement window, shown in figure 39, will appear, indicating that opening a file is required to continue right-click pop-up menu analyses, but auditory risk analyses can continue to be performed.

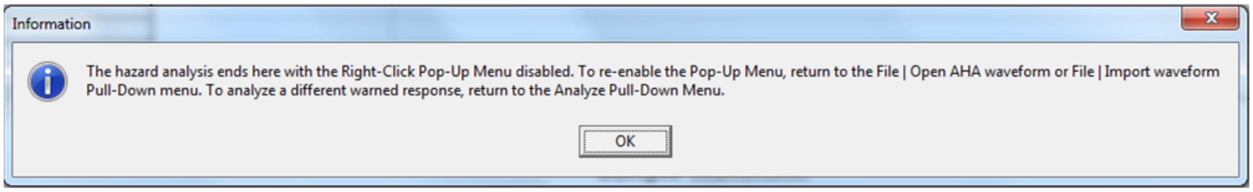


Figure 39. Indication that a file must be opened to continue analyses.

5. Software Output

As described earlier, after a waveform has been analyzed for risk, a new file is written in the Data Files folder (or whatever folder contained the original waveform being analyzed) with a HAZ extension. This file includes a chart, overwritten during each analysis of a waveform of the same name,* which contains the numeric results of the risk calculation. These HAZ files are space-delimited ASCII files that may be opened with a spreadsheet or word processor program of your choice. Table 1 is the output of the TestImpulse.AHA unwarned analysis, opened with Excel. In Excel, when the HAZ file is selected to be opened, the Excel Text Import Wizard places the HAZ file elements in separate spreadsheet cells. In on-screen reporting of the auditory risk from any analysis, AHAAH always reports the highest risk value occurring in the HAZ file, regardless of location along the cochlea. In the example analysis shown in table 1, the auditory risk value is 812 ARUs in bin number 8, located 3.94 cm from the basal end of the cochlea.

Table 1. Example of AHAAH hazard calculation output.

BIndex	Frequency (kHz)	Hazard (AHU)	Distance (cm)
1	11.76	184.1	0.425
2	10.06	202.1	0.55
3	8.6	281.1	0.675
4	7.36	401.6	0.8
5	6.29	476.8	0.925
6	5.38	577.4	1.05
7	4.6	723.5	1.175

*You must rename the file to save the results for a particular analysis.

Table 1. Example of AHAAH hazard calculation output (continued).

BIndex	Frequency (kHz)	Hazard (AHU)	Distance (cm)
8	3.94	812.0	1.3
9	3.37	790.1	1.425
10	2.88	651.2	1.55
11	2.46	472.0	1.675
12	2.11	386.1	1.8
13	1.8	318.8	1.925
14	1.54	308.3	2.05
15	1.32	284.6	2.175
16	1.13	259.7	2.3
17	0.97	226.1	2.425
18	0.83	176.6	2.55
19	0.71	134.6	2.675
20	0.6	99.3	2.8
21	0.52	68.6	2.925
22	0.44	41.7	3.05
23	0.38	20.4	3.175

Note: BIndex is the number of the site along the basilar membrane; frequency (kHz) is the ideal tuning for that site; hazard (ARU) is the risk associated with that site; and distance (cm) is the distance along the basilar membrane from the basal end.

6. For Further Information

There are numerous resources for learning more about the theory, development, and validation of the AHAAH model. Appendix D is a chronologically organized bibliography of publications and presentations on these topics. You may also visit the AHAAH Web pages on ARL's Web site <http://www.arl.army.mil/www/default.cfm?page=343> to find reports on the supporting scientific research and applications of AHAAHs. As of the date of publication of this report, the pages were under the Human Research and Engineering Directorate organizational section of the ARL Web site.

7. Conclusion

The AHAAH model, as implemented in the accompanying software, is a valuable tool for estimating the auditory hazard of impulsive acoustic events. The AHAAH model:

- Yields more physically realistic results than previous methodologies,
- Better correlates with the experimental observations of the Albuquerque blast over-pressure study,

- Accounts for the variable condition of the auditory reflex,
- Accounts for the detailed time-dependence of the incident waveform,
- Evaluates the nonlinear energy transfer across the middle ear, and
- Determines auditory risk based on observationally validated displacements of the basilar membrane.

AHAAH's application of these analytical details provides a more accurate estimate of quantities such as the allowable number of rounds that can be fired in training and firing scenarios (such as firing from within enclosed spaces). By observing the AHAAH hazard analysis movie, which animates the detailed movement of the basilar membrane due to the impinging waveform, weapons developers and safety engineers can determine what portions of the waveform produce the largest contributions to hearing damage and develop waveform modifications to effectively mitigate the more severe impacts to the hearing of individuals exposed to those waveforms.

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Appendix A. Stability of the Auditory Hazard Assessment Algorithm for Humans (AHAAH) Model

It has been brought to our attention that there may be a misunderstanding within the technical community concerning Auditory Hazard Assessment Algorithm for Humans (AHAAH). We understand several parties have expressed concern that AHAAH is “a moving target,” being adjusted each time a problem is found with the model. At two levels, that is simply not true.

First, the core programming—that dealing with the propagation of sound into the ear and the calculation of risk—has been unchanged since the model was publicly released in the mid-1990s.

Secondly, it has always been our expectation that if data are produced showing that the model’s predictions are in error, it would be in keeping with the best principles of science and model-making to determine which properties of the ear have been incorrectly represented in the model and to change them so that the model’s performance matches all available data as well as possible. We await the arrival of such data.

The issue regarding adjustments to AHAAH has, no doubt, come about because there have been numerous changes made to the overall AHAAH software package. These changes introduce new features that include hearing protection, improve how the program displays calculated results, and improve the code so that it does not become unstable under unusual circumstances.

The most prominent changes have been associated with the hearing protection module. The AHAAH model requires a waveform for input, in the free field (if no protection is worn), at the ear canal entrance, or at the eardrum location if hearing protection is worn. A measured waveform on an acoustical test fixture (ATF; manikin) or human subjects might be used. Lacking human or ATF data for the AHAAH model to process, some method of calculating the waveform under the hearing protection device (HPD) was required. Initially, a minimum phase approach was used to calculate the waveform for processing (attenuations “typical” of single and double HPDs were used—a considerable improvement over the single number adjustment for hearing protection found in MIL-STD-1747D).

More recently, a full electroacoustic HPD model was developed that allows calculations with specific types of hearing protectors, including those that are nonlinear. In summary, the hearing protection module has been adjusted many times to better represent the full range of hearing protector effects, but the results produced by the core AHAAH model have not changed since it was originally released.

A few years ago, a feature was added that allows the calculation of hazard for any percentile of susceptibility (the basic concept is inherent in the model). While the U.S. Army might choose to protect the 95th percentile ear, other agencies or governments might choose some other level of protection, or scientists may wish to calculate effects on other populations (and they are free to do so).

There have also been minor changes in the computational algorithms used in AHAAH to correct computational problems as they were discovered. We found that calculations with double hearing protection caused the waveform under the combined protector to be much longer than the initial waveform (a reasonable outcome). In order to avoid the error that would result (the longer waveform would "wrap around" and appeared to be additional information at the beginning of the waveform), the end of the waveform should be padded with "zeros." Recent versions of the AHAAH model do this automatically (previously, it was a manual process). If in doubt, append zeros to the end of the waveform. (It is not unreasonable for 75% of the waveform to be zeros.) The acuity of the AHAAH model has improved as data acquisition equipment advanced and equipment costs were reduced. Currently, the recommended sampling rate for acquiring the waveform is 192 kHz (minimum). This sampling rate is adequate to avoid errors that might result from undersampling. As recently as 10 years ago, data were recorded at sampling rates as low as 44 kHz.

In spite of these changes, we are still using the same basic algorithms. However, the fix for "wrap-around" did produce an unintended consequence. Namely, the numerical integrations in the outer and middle ear use the fourth-order Runga-Kutta method with a step size control based on the Richardson criterion (i.e., calculation over a time interval is repeated with half the step size and the results are compared). This method works well unless the waveform ends with appended zeros, in which case the procedure stops. To prevent this, we added dithering noise to the incoming waveform at a level below the sampling resolution. This noise causes slight changes (in the fourth significant digit) in the calculated results from run to run.

Finally, we note that some features of the AHAAH model might result in "surprises" in the data analysis and make it appear that the model had changed. The instructions for the use of the model cover these issues; however, experience shows that users may make the following common mistakes:

- **Establish Start**: The *Establish Start* function on the right-click pop-up menu allows the user to synchronize the aural reflex onset with a point on the waveform. If this is not done consistently, then the unwarned hazard can change while the warned hazard does not change.
- **Measurement Location**: The waveform to be analyzed should be measured at one of three locations designated by a "1" for free field, "2" for ear canal entrance, and "3" for eardrum (or ATF microphone). When a waveform is first imported, this location number in the header of the AHA file defaults to "1" (assumes free-field recording). If another location is appropriate, the user needs to change the digit to reflect the appropriate location and save the waveform after editing. If this is not done, the waveform might be applied at the wrong location, generating an erroneous result.

- **Waveform Importation**: During the importation of a waveform, the default sampling rate is set at 200 kHz. If the imported waveform is a WAV file, then AHAAH reads the sampling frequency from the WAV file header. Otherwise, the default sampling rate may not be correct, and that will cause erroneous results.
- **Taper Ends**: If the waveform is not tapered at the ends, then end-effect distortions can occur, generating an erroneous result.

Finally, we note that AHAAH began as a research tool and was designed to be as flexible as possible so that any researcher might test its provisions and perhaps develop a better model. With that in mind, all of the model's variables were made accessible in the "man.coe" file. That file also contains "features" that are not commonly used but which can be turned off or on at will. (For example, it is possible to print all the hazard values calculated, not just the highest, which is what is commonly reported.) In the world of damage risk criteria, however, too many options are the enemy of a standard. Hence, the version of AHAAH intended for standardization has been structured to minimize choices that might result in an inaccurate calculation. So, if the "man.coe" file is modified from its original form, AHAAH will indeed be a moving target (but of your own making). In that regard, it might be useful to have a copy of the original "man.coe" file stored as "adam.coe"—the original man.

Even though features have been added to the AHAAH model, the basic calculation of hazard has not been changed. Nonetheless, because the model is structured to be conformal with the ear's anatomy, if new data are produced, the model is in a form that promotes improvement.

Appendix B. List of Hearing Protectors Implemented in Auditory Hazard Assessment Algorithm for Humans (AHAAH)

The Auditory Hazard Assessment Algorithm for Humans (AHAAH) contains an extensive list of hearing protectors that can be applied when performing auditory risk evaluation. AHAAH contains a list of default hearing protectors as well as other hearing protectors that have been characterized based on available data. Table B-1 lists the default hearing protectors offered in AHAAH.

Table B-1. Descriptions of default hearing protectors.

Default Hearing Protection	**Style**	**Type**	**Typical Application**	**Example of an Acceptable Product**
Default 01	Plug	Standard level – dependent single hearing protection	Ground Soldier needing hearing protection but not electronic communications (e.g., dismounted Soldier firing small arms)	Combat arms earplug (level: dependent mode)
Default 02	Plug	Standard level – independent single hearing protection	Ground Soldier operating in the vicinity of generators, vehicles, or other sources of steady-state noise	Combat arms earplug (level: independent mode)
Default 03	Muff	Standard Tactical Communication and Protective System (TCAPS) - hearing protection with electronic communications)	Ground Soldier needing hearing protection with electronic communications (e.g., dismounted Soldier firing small arms)	COMTAC III earmuff
Default 04	Muff	Standard TCAPS (hearing protection with electronic communications)	Combat vehicle crewmember in a wheeled combat vehicle	Product Improved Combat Vehicle Crewmember Helmet (PICVC)
Default 05	Plug + Muff	Standard double hearing protection	A Soldier in a tracked combat vehicle	PICVC headset (with Active Noise Reduction [ANR] on) + standard level: independent earplug
Default 06	Plug + Muff	Standard double hearing protection	Ground Soldier firing a shoulder-fired weapon, especially from within enclosures	Standard double protection
Default 07	Plug + Muff	Standard double hearing protection	Apache (AH-64) helicopter crewmembers	Integrated Helmet and Display Sight System (IHADSS)-integrated helmet + Communication Enhancement and Protection System (CEPS) earplug
Default 08	Plug + Muff	Standard double hearing protection	Helicopter crewmembers (except Apache)	HGU-56/P-integrated helmet + CEPS earplug

Table B-1. Descriptions of default hearing protectors (continued).

Default Hearing Protection	Style	Type	Typical Application	Example of an Acceptable Product
Default 09	Plug	Standard single hearing protection	Other unspecified applications requiring single hearing protection against weapon-firing noise	Combat arms earplug (level: dependent mode)
Default 10	Plug	Standard single hearing protection	Other unspecified applications requiring single hearing protection against sources of steady-state noise	Combat arms earplug (level: independent mode)
Default 11	Plug + Muff	Standard double hearing protection	Other unspecified applications requiring double hearing protection	Standard double protection

As the man.coe file contains parameters that specify AHAAH performance, the HPD Atten.txt file provides the electroacoustic circuit values that specify the characteristic of individual models of hearing protectors. Hearing protectors are characterized by the physical quantities defined and described in table B-2.

Table B-2. Hearing protection module parameters (found in the HPD Atten.txt file).

Electroacoustic Circuit Values	Default Value	Units	Description or Purpose
Lcup	*	$g.cm^{-4}$	Mass of hearing protector cup
Kcup	*	$cm^{5}.dyne^{-1}$	Compliance of hearing protector cup
Kskin	*	$cm^{5}.dyne^{-1}$	Compliance of skin contacting hearing protector
Rskin	*	$dyne.sec.cm^{-5}$	Resistance in skin
Kcush	*	$cm^{5}.dyne^{-1}$	Compliance of hearing protector cushion
Rcush	*	$dyne.sec.cm^{-5}$	Resistance in hearing protector cushion
Lleak	*	$g.cm^{-4}$	Mass of air in leak path
Rleak	*	$dyne.sec.cm^{-5}$	Resistance in leak path
Kmat	*	$cm^{5}.dyne^{-1}$	Compliance of hearing protector material
Lmat	*	$g.cm^{-4}$	Mass of hearing protector material
Rmat	*	$dyne.sec.cm^{-5}$	Resistance in hearing protector material
Kcush2	*	$dyne.sec^{3}.cm^{-11}$	Compliance of nonlinear hearing protector cushion
Rcush2	*	$dyne.sec.cm^{-5}$	Resistance of nonlinear hearing protector cushion
Kmat2	*	$dyne.sec^{3}.cm^{-11}$	Compliance of nonlinear hearing protector material
Rmat2	*	$dyne.sec.cm^{-5}$	Resistance of nonlinear hearing protector material

*Values of the properties of hearing protectors are specified in table B-3 for each individual hearing protector model.

Table B-3 shows data for all hearing protection devices (HPDs) available in AHAAH's Hearing Protection Module. The last four values are all zero; they represent coefficients for cubic force terms for nonlinear behavior for the future incorporation of nonlinear force terms in the descriptions of hearing protector performance.

The 11 default hearing protection configurations listed in table B-1 are listed first in table B-3. This table duplicates the data file entitled "HPD Atten.txt" used in the AHAAH software to operate the Hearing Protection Module. Attenuation data and standard deviations for scores of hearing protection configurations are shown. Category, status, and style codes are used by the hearing protection module (HPM) to generate drop-down menus when *Apply Hearing Protection* is selected. The electroacoustic circuit values are used in the HPM to predict HPD response.

A complete mathematical description of the electroacoustic engineering model of hearing protectors is given by Kalb.[1]

[1] Kalb, J. T. A Hearing Protector Model for Predicting Impulsive Noise Hazard. *159th Meeting of the Acoustical Society of America*; NOISE-CON 2010; Baltimore, MD, 2010. http://www.arl.army.mil/www/pages/343/Kalb_NOISE_CON_2010_HearingProtectionModule.pdf (accessed 17 December 2013).

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values.

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
Electro-Acoustic Circuit Values	Lcup	Kcup	Kskin	Rskin	Kcush	Rcush	Lleak	Rleak	Kmat	Lmat	Rmat	Kcush2	Rcush2	Kmat2	Rmat2
DEFAULT 01 (PLUG)	0.125	0.25	0.5	1	2	4	8				D01	U	N	DEFAULT 01 (PLUG)	
	0	-1	-5	-17	-23	-21	-21								
	3	3	3	4	4	4	6								
	1.03E+01	1.00E+05	2.50E+11	2.03E+06	2.50E+10	2.03E+05	1.01E-02	3.18E+01	6.94E+05	2.01E-04	1.81E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DEFAULT 02 (PLUG)	0.125	0.25	0.5	1	2	4	8				D02	U	P	DEFAULT 02 (PLUG)	
	-24	-24	-25	-28	-30	-32	-43								
	4	5	7	6	5	6	5								
	1.03E+01	1.00E+08	6.84E+09	2.10E+06	6.84E+08	2.10E+05	2.53E+08	1.59E+08	3.06E+09	4.76E+00	8.18E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DEFAULT 03 (MUFF)	0.125	0.25	0.5	1	2	4	8				D03	U	M	DEFAULT 03 (MUFF)	
	-6	-11	-16	-27	-28	-30	-35								
	4	3	4	3	5	5	5								
	4.05E-02	1.35E+06	4.13E+07	1.27E+03	7.87E+07	3.98E+03	3.80E-01	1.67E+03	1.90E+08	1.04E-01	2.97E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DEFAULT 04 (MUFF)	0.063	0.125	0.25	0.5	1	2	4	8			D04	U	M	DEFAULT 04 (MUFF)	
	-9.3	-12.1	-18.8	-23.1	-31.5	-32.3	-42.5	-43.6							
	2.8	1.3	1.8	2	2.8	2.1	3.5	2.4							
	4.05E-02	1.45E+05	1.02E+07	6.88E+02	8.11E+07	6.88E+03	4.07E-02	6.06E+02	3.51E+07	1.79E-02	5.30E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DEFAULT 05 (PLUG + MUFF)	0.125	0.25	0.5	1	2	4	8				D05	U	D	DEFAULT 05 (PLUG + MUFF)	
	-33.9	-40.7	-47	-38.7	-38.1	-48.7	-53.9								
	6	6.9	7.8	5.1	4.2	5.3	4.9								
	4.05E-02	2.14E+05	1.38E+07	9.86E+02	1.30E+08	9.41E+03	2.56E+00	5.94E+03	2.14E+08	1.64E-01	5.92E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DEFAULT 06 (PLUG + MUFF)	0.125	0.25	0.5	1	2	4	8				D06	U	OD	DEFAULT 06 (STANDARD DOUBLE MEAN - ONE SIGMA VALUES)	
	-21.7	-21.7	-28.4	-29.3	-34.3	-42.6	-39.8								
	0	0	0	0	0	0	0								
	4.05E-02	1.44E+05	7.87E+06	8.36E+02	1.98E+07	3.63E+03	1.61E-01	1.53E+03	2.55E+07	1.50E-02	2.49E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DEFAULT 07 (PLUG + MUFF)	0.125	0.25	0.5	1	2	4	8				D07	U	D	DEFAULT 07 (PLUG + MUFF)	

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
	-24	-25.2	-31.6	-31.3	-39.5	-50.5	-55.6							HGU-56/P + CEPS	
	7.5	6.8	6	4	4.3	5.7	5.2							USAARL EMAIL 23 MAY 2005	
	4.05E-02	1.00E+05	1.72E+06	8.01E+02	1.72E+05	1.01E+03	2.81E+00	5.31E+02	1.77E+07	7.04E-03	7.08E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DEFAULT 08 (PLUG + MUFF)	0.125	0.25	0.5	1	2	4	8				D08	U	D	DEFAULT 08 (PLUG + MUFF)	
	-24	-25.2	-31.6	-31.3	-39.5	-50.5	-55.6							HGU-56/P +CEPS	
	0	0	0	0	0	0	0							USAARL EMAIL 23 MAY 2005 ANSI S12.6-1997	
	4.05E-02	1.05E+05	3.76E+06	1.21E+03	5.37E+06	2.00E+03	1.06E+00	2.84E+03	1.86E+08	1.40E-01	2.04E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DEFAULT 09 (PLUG)	0.125	0.25	0.5	1	2	4	8				D09	U	N	DEFAULT 09 (PLUG)	
	0	-1	-5	-17	-23	-21	-21								
	3	3	3	4	4	4	6								
	1.03E+01	1.00E+05	2.50E+11	2.03E+06	2.50E+10	2.03E+05	1.01E-02	3.18E+01	6.94E+05	2.01E-04	1.81E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DEFAULT 10 (PLUG)	0.125	0.25	0.5	1	2	4	8				D10	U	P	DEFAULT 10 (PLUG)	
	-24	-24	-25	-28	-30	-32	-43								
	4	5	7	6	5	6	5								
	1.03E+01	1.00E+08	6.84E+09	2.10E+06	6.84E+08	2.10E+05	2.53E+08	1.59E+08	3.06E+09	4.76E+00	8.18E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DEFAULT 11 (PLUG + MUFF)	0.125	0.25	0.5	1	2	4	8				D11	U	N	DEFAULT 11 (PLUG + MUFF)	
	-21.7	-21.7	-28.4	-29.3	-34.3	-42.6	-39.8								
	0	0	0	0	0	0	0								
	4.05E-02	1.44E+05	7.87E+06	8.36E+02	1.98E+07	3.63E+03	1.61E-01	1.53E+03	2.55E+07	1.50E-02	2.49E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ACAPS ANR OFF TYPE B HEADSET MEAN - ONE SIGMA VALUES	0.125	0.25	0.5	1	2	4	8				P	U	M	ACAPS ANR OFF TYPE B HEADSET MEAN - ONE SIGMA VALUES	
	-12	-17	-17	-23	-28	-30	-35							GENTEXCORP.COM 3 APR 2000	
	0	0	0	0	0	0	0							PEAT, EAR CANAL ENTRANCE, MIL STD 912	
	4.05E-02	4.47E+05	6.99E+06	2.36E+03	2.77E+06	1.59E+03	2.00E+00	9.45E+02	2.47E+07	1.33E-02	5.79E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
CLASSIC SUPERFIT 30 MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	CLASSIC SUPERFIT 30 MEAN VALUES	
	-32.9	-37.5	-41.4	-40	-36.4	-43.9	-45.2	-48.2	-48.1					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	1.03E+01	1.45E+07	1.44E+10	9.23E+05	1.44E+09	9.23E+04	3.68E+07	2.31E+08	5.20E+09	4.19E+00	8.49E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CLASSIC SUPERFIT 33 MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	CLASSIC SUPERFIT 33 MEAN VALUES	
	-37.7	-43	-47	-43.7	-38.2	-44.5	-45.4	-49.1	-48.4					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	1.03E+01	1.32E+07	3.23E+10	1.22E+06	3.23E+09	1.22E+05	4.71E+02	7.88E+05	3.51E+09	1.61E+00	8.26E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
COMBAT ARMS DOUBLE-ENDED CLOSED MODE MEAN VALUES (3M)	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	COMBAT ARMS DOUBLE-ENDED CLOSED MODE MEAN VALUES (3M)	
	-32.7	-31.8	-33	-32	-34.5	-37.3	-38.9	-43.8	-43.3					3M PRODUCT DATA SHEET	
	0	0	0	0	0	0	0	0	0					ANSI S 3.19-1974 EAR LAB DATA	
	1.03E+01	4.07E+07	2.43E+10	1.96E+06	2.43E+09	1.96E+05	1.64E+04	8.16E+06	6.14E+09	2.90E+00	1.58E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
COMBAT ARMS DOUBLE-ENDED CLOSED MODE MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	P	COMBAT ARMS DOUBLE-ENDED CLOSED MODE MEAN VALUES	
	-24	-24	-25	-28	-30	-32	-43							AFRL-RH-WP-TR-2009-0031	
	0	0	0	0	0	0	0							ANSI 12.6-1997	
	1.03E+01	8.71E+07	1.65E+10	4.74E+06	1.65E+09	4.74E+05	2.21E+08	2.77E+08	4.81E+09	7.75E+00	1.95E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
COMBAT ARMS DOUBLE-ENDED OPEN MODE MEAN + 1 SD VALUES	0.125	0.25	0.5	1	2	4	8				P	U	N	COMBAT ARMS DOUBLE-ENDED OPEN MODE MEAN + 1 SD VALUES	
	0	-1	-5	-17	-23	-21	-21							AFRL-RH-WP-TR-2009-0031	
	0	0	0	0	0	0	0							ANSI 12.6-1997	
	1.03E+01	1.00E+05	2.50E+11	2.03E+06	2.50E+10	2.03E+05	1.01E-02	3.18E+01	6.94E+05	2.01E-04	1.81E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
COMBAT ARMS DOUBLE-ENDED OPEN MODE MEAN VALUES (3M)	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	N	COMBAT ARMS DOUBLE-ENDED OPEN MODE MEAN VALUES (3M)	
	-4.7	-4.2	-6	-9.5	-16.7	-18.6	-16.3	-16.7	-17.2					3M PRODUCT DATA SHEET	
	0	0	0	0	0	0	0	0	0					ANSI S 3.19-1974 EAR LAB DATA	
	1.03E+01	1.00E+05	2.61E+10	2.37E+06	2.61E+09	2.37E+05	5.17E-03	4.55E+01	6.94E+05	3.14E-04	1.58E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
COMBAT ARMS DOUBLE-ENDED OPEN MODE MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	N	COMBAT ARMS DOUBLE-ENDED OPEN MODE MEAN VALUES	
	0	-1	-5	-17	-23	-21	-21							AFRL-RH-WP-TR-2009-0031	
	0	0	0	0	0	0	0							ANSI 12.6-1997	
	1.03E+01	1.00E+05	2.50E+11	2.03E+06	2.50E+10	2.03E+05	1.01E-02	3.18E+01	6.94E+05	2.01E-04	1.81E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
COMBAT ARMS SELECTOR DIAL CLOSED MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	COMBAT ARMS SELECTOR DIAL CLOSED MEAN VALUES	
	-4.1	-4.9	-10.1	-17	-22.9	-29.9	-27.4	-24.4	-24.4					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	1.03E+01	1.00E+08	5.19E+08	1.21E+06	5.19E+07	1.20E+05	2.53E+08	3.18E+08	2.41E+09	9.94E-01	3.33E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
COMBAT ARMS SELECTOR DIAL OPEN MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	N	COMBAT ARMS SELECTOR DIAL OPEN MEAN VALUES	
	-4.1	-4.9	-10.1	-17	-22.9	-29.9	-27.4	-24.4	-24.4					30 MAY 2012 EMAIL	
	2.9	2.9	2.9	3.8	5.1	2.7	3.4	4	5					ANSI S3.1 1974 EARCAL	
	1.03E+01	1.00E+05	2.43E+10	2.29E+06	2.43E+09	2.29E+05	1.01E-02	6.37E+01	1.68E+06	7.04E-04	1.77E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
COMBAT ARMS WITH ROCKER PANEL SWITCH CLOSED MEAN VALUES (3M)	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	COMBAT ARMS WITH ROCKER PANEL SWITCH CLOSED MEAN VALUES (3M)	
	-30.3	-28.7	-32.2	-31.9	-31.7	-38	-35.1	-31.9	-37.8					3M PRODUCT DATA SHEET	
	3.4	3.9	3.4	3.8	3	4.4	4.8	5.4	4.3					ANSI S 3.19-1974 EAR LAB DATA	
	1.03E+01	7.94E+07	1.92E+10	2.60E+06	1.92E+09	2.60E+05	2.01E+08	2.53E+08	6.23E+09	4.44E+00	4.18E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
COMBAT ARMS WTIH ROCKER PANEL SWITCH OPEN MEAN VALUES (3M)	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	N	COMBAT ARMS WTIH ROCKER PANEL SWITCH OPEN MEAN VALUES (3M)	
3M PRODUCT DATA SHEET	-4.1	-4.5	-11	-18.7	-24.9	-29.8	-25.8	-18.7	-26.5					3M PRODUCT DATA SHEET	
	2.7	2.8	3.9	3.2	3.3	2.7	3.3	3.6	3.3					ANSI S 3.19-1974 EAR LAB DATA	
	1.03E+01	1.00E+05	2.43E+10	2.29E+06	2.43E+09	2.29E+05	5.17E-03	4.55E+01	2.41E+06	1.77E-03	1.67E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
COMTAC II WITH FOAM CUPS PASSIVE MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	M	COMTAC II WITH FOAM CUPS PASSIVE MEAN VALUES	
	-10	-16	-21	-28	-25	-40	-41							AFRL-RH-WP-TR-2009-0031	
	0	0	0	0	0	0	0							ANSI 12.6-1997	
	4.05E-02	2.24E+05	8.89E+05	1.56E+03	8.89E+06	3.04E+02	6.22E-01	1.24E+03	2.25E+07	8.99E-03	4.52E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DAVID CLARK 19A HEADPHONE MEAN - 1 SIGMA VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	DAVID CLARK 19A HEADPHONE MEAN - 1 SIGMA VALUES	
	-16	-27	-37	-39	-40	-40	-40	-36	-31					MIL-HDBK-759 12 MAR 1975 P.403	
	0	0	0	0	0	0	0	0	0						
	4.05E-02	1.00E+05	2.29E+07	2.62E+03	5.27E+06	2.57E+03	5.42E-01	5.17E+02	1.01E+07	4.02E-03	8.08E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DH132 + EAR MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	D	DH132 + EAR MEAN VALUES	
	-33.9	-40.7	-47	-38.7	-38.1	-48.7	-53.9							USAARL 93-10 JANUARY 1993	
	0	0	0	0	0	0	0								
	4.05E-02	1.00E+05	2.75E+07	1.18E+03	2.10E+07	9.77E+02	2.37E+00	3.43E+03	9.99E+07	4.03E-02	8.03E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
DH132 + SINGLE FLANGE MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	D	DH132 + SINGLE FLANGE MEAN VALUES	
	-27.6	-34.2	-34	-32	-39	-47.9	-50.8							USAARL 93-10 JANUARY 1993	
	0	0	0	0	0	0	0								
	4.05E-02	1.00E+05	5.88E+06	7.76E+02	1.00E+07	1.23E+03	1.16E+00	2.83E+03	9.99E+07	1.38E-01	1.49E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DH-132 TANKER'S HELMET AND TRIPLE FLANGE EARPLUG MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	D	DH-132 TANKER'S HELMET AND TRIPLE FLANGE EARPLUG MEAN VALUES	
	-32	-37.1	-40.2	-34.9	-34	-43.1	-47.4							USAARL REPORT NO. 93-10, JAN 1993	
	0	0	0	0	0	0	0								
	4.05E-02	1.23E+05	1.32E+07	4.30E+02	7.58E+07	3.34E+03	2.28E+00	5.29E+03	3.53E+07	1.85E-02	8.09E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EAR FOAM MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	EAR FOAM MEAN VALUES	
	-27.8	-26.6	-29.2	-27.8	-30.4	-39	-39.3	-41	-41.2						
	0	0	0	0	0	0	0	0	0					5/21/97 USAARL DATA	
	1.03E+01	4.27E+07	1.43E+10	1.24E+06	1.43E+09	1.24E+05	1.08E+08	6.79E+08	5.32E+09	2.77E+00	1.17E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EAR ULTRAFIT WWW.AEARO.COM MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	EAR ULTRAFIT WWW.AEARO.COM MEAN VALUES	
	-29.4	-29.3	-30.7	-29.5	-32.8	-37.9	-38	-40.9	-43.8						
	0	0	0	0	0	0	0	0	0						
	1.03E+01	4.15E+07	1.53E+10	1.62E+06	1.53E+09	1.62E+05	7.31E+02	1.74E+06	6.04E+09	5.40E+00	1.26E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ELVEX QUATRO MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	ELVEX QUATRO MEAN VALUES	
	-29.4	-30.8	-31.8	-32.1	-33.1	-37.8	-36.8	-39.5	-39.5					ELVEX WEBSITE	
	0	0	0	0	0	0	0	0	0					ANSI S 3.19-1974 MICHAEL AND ASSOCIATES	
	1.03E+01	4.68E+07	2.31E+10	2.15E+06	2.31E+09	2.15E+05	5.55E+02	1.61E+06	5.38E+09	2.77E+00	1.09E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
FINGERS IN EAR (HEL) MEAN - ONE SIGMA VALUES	0.125	0.25	0.5	1	2	3	4	6	8		P	O	OP	FINGERS IN EAR (HEL) MEAN - ONE SIGMA VALUES	
	-35	-28	-25	-28	-32	-28	-32	-33	-35					MIL-HDBK-759 12 MAR 1975 P.403	
	0	0	0	0	0	0	0	0	0						
	1.03E+01	5.89E+07	3.98E+10	1.52E+06	3.98E+09	1.52E+05	1.49E+08	9.37E+07	3.57E+09	1.86E+00	6.90E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
HGU-56/P + CEPS	0.125	0.25	0.5	1	2	4	8				P	U	D	HGU-56/P + CEPS	
	-24	-25.2	-31.6	-31.3	-39.5	-50.5	-55.6							USAARL EMAIL 23 MAY 2005	
	7.5	6.8	6	4	4.3	5.7	5.2							ANSI S12.6-1997 METHOD A	
	4.05E-02	1.00E+05	1.72E+06	7.31E+02	1.72E+05	1.01E+03	1.01E+02	3.18E+03	1.77E+07	7.04E-03	7.08E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
HGU-56/P	0.125	0.25	0.5	1	2	4	8				P	U	M	HGU-56/P	
	-11.7	-12.6	-16.6	-21.5	-29.7	-34.4	-38.9							USAARL EMAIL 23 MAY 2005	
	9.3	5.7	6.4	4.3	3.6	6	11.1							ANSI S12.6-1997 METHOD A	
	4.05E-02	1.00E+05	9.92E+06	1.27E+03	9.92E+06	1.27E+03	5.17E-03	1.14E+02	5.52E+06	1.42E-03	3.58E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MSA SORDIN PASSIVE MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	M	MSA SORDIN PASSIVE MEAN VALUES	
	-9	-13	-18	-23	-25	-34	-41							AFRL-RH-WP-TR-2009-0031	
	0	0	0	0	0	0	0							ANSI 12.6-1997	
	4.05E-02	2.82E+05	2.04E+06	1.94E+03	2.00E+06	8.59E+02	7.14E-01	9.59E+02	1.56E+07	1.55E-02	7.26E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MT15H67B-01 TACTICAL 6-S MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	MT15H67B-01 TACTICAL 6-S MEAN VALUES	
	-11	-17.1	-27.2	-35	-31.1	-39.4	-40.7	-38	-36.5					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	4.05E-02	1.42E+05	1.08E+07	5.65E+02	4.04E+07	2.63E+03	1.85E-01	5.98E+02	1.68E+07	6.93E-03	2.06E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MT15H67BB SOUND TRAP SLIM LINE MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	MT15H67BB SOUND TRAP SLIM LINE MEAN VALUES	
	-11.5	-15.6	-23.1	-27	-29.8	-37.4	-38.6	-35.6	-34.9					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	4.05E-02	2.21E+05	7.18E+06	7.11E+02	1.80E+07	5.13E+03	1.81E-01	9.05E+02	2.19E+07	8.76E-03	2.62E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
MT15H67FB SOUNDTRAP MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	MT15H67FB SOUNDTRAP MEAN VALUES	
	-11.4	-17.2	-27.3	-35.3	-34.5	-37.5	-39.7	-39.1	-37.1					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	4.05E-02	1.66E+05	1.98E+07	7.69E+02	1.59E+07	2.95E+03	2.39E-01	7.14E+02	2.38E+07	9.47E-03	2.55E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MT16H044F COMTAC IV (CLASSIC TIPS) MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	MT16H044F COMTAC IV (CLASSIC TIPS) MEAN VALUES	
	-36.8	-37.4	-41.4	-42.7	-35.2	-42.3	-44.2	-44.5	-45.1					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	4.05E-02	1.05E+05	5.88E+07	2.38E+03	2.15E+07	8.91E+02	2.65E+05	1.67E+06	3.45E+07	1.37E-02	2.75E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MT16H044F COMTAC IV (PELTIPS) MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	MT16H044F COMTAC IV (PELTIPS) MEAN VALUES	
	-33.3	-32.7	-33.6	-31.5	-31.9	-34.2	-31.8	-31.1	-33.5					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	4.05E-02	2.51E+05	2.86E+07	1.39E+03	8.90E+07	9.50E+02	2.08E+03	2.28E+04	2.49E+07	9.94E-03	2.39E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MT16H210F TACTICAL SPORT MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	MT16H210F TACTICAL SPORT MEAN VALUES	
	-13.5	-18.3	-26.6	-26.5	-29.6	-35.6	-38.2	-38.8	-39.4					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	4.05E-02	2.24E+05	8.24E+06	6.95E+02	1.37E+07	2.40E+03	3.64E-01	1.15E+03	2.55E+07	1.22E-02	4.84E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MT17H682BB COMTAC ACH MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	MT17H682BB COMTAC ACH MEAN VALUES	
	-19.1	-17.9	-29.6	-33.2	-32.7	-42.8	-39.1	-37.4	-39.3					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	4.05E-02	1.66E+05	1.53E+07	1.17E+03	2.49E+07	2.75E+03	1.61E-01	1.32E+03	2.93E+07	1.31E-02	2.49E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
MT17H682FB COMTAC III WITH DAMPING PAD 79 MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	MT17H682FB COMTAC III WITH DAMPING PAD 79 MEAN VALUES	
	-14.2	-18.4	-28.9	-31.8	-29.4	-37.4	-37.6	-36.8	-37.8					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	4.05E-02	2.48E+05	1.81E+07	8.91E+02	1.72E+07	2.04E+03	4.16E-01	1.35E+03	4.38E+07	1.81E-02	3.57E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MT17H682P808BB WITH FOAM CUSHIONS MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	MT17H682P808BB WITH FOAM CUSHIONS MEAN VALUES	
	-19.1	-16.8	-26.7	-33.1	-31.6	-40.3	-35.9	-40.5	-41.8					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	4.05E-02	1.68E+05	3.77E+07	7.54E+02	1.61E+07	1.78E+03	1.06E-01	1.21E+03	3.61E+07	1.44E-02	2.89E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MT17H682P808BB WITH GEL CUSHIONS MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	MT17H682P808BB WITH GEL CUSHIONS MEAN VALUES	
	-17.3	-16.7	-25	-31.2	-32.4	-39	-35.4	-38.4	-40.5					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	4.05E-02	2.13E+05	3.86E+07	6.27E+02	1.11E+07	2.14E+03	1.35E-01	1.39E+03	6.02E+07	3.43E-02	5.76E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MT21H61FA-02 BASIC MT31H61FA092 BASIC MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	MT21H61FA-02 BASIC MT31H61FA092 BASIC MEAN VALUES	
	-11.9	-12.3	-19.6	-25.2	-26.1	-41.7	-46.3	-38	-39.2					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	4.05E-02	1.51E+05	4.85E+06	2.25E+02	4.64E+06	1.95E+03	9.59E-02	5.80E+02	2.73E+07	1.42E-02	2.52E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NO MUFF	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	O	OM	NO MUFF	
	0	0	0	0	0	0	0	0	0						
	0	0	0	0	0	0	0	0	0						
	4.05E-02	8.13E+07	1.35E+06	1.83E+04	1.35E+06	1.83E+04	1.38E+02	5.29E+04	0.00E+00	8.24E-04	3.70E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
NO PLUG	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	O	OP	NO PLUG	
	0	0	0	0	0	0	0	0	0						
	0	0	0	0	0	0	0	0	0						
	1.03E+01	1.00E+08	6.53E+10	2.24E+06	6.53E+09	2.24E+05	2.53E+08	1.59E+08	0.00E+00	6.33E-03	1.03E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	M	PELTOR COMTAC WITH GEL CUPS PASSIVE MEAN VALUES	
	-6	-11	-16	-27	-28	-30	-35							AFRL-RH-WP-TR-2009-0031	
	0	0	0	0	0	0	0							ANSI 12.6-1997	
	4.05E-02	8.32E+05	2.95E+07	1.27E+03	2.55E+07	6.82E+03	5.27E-01	1.75E+03	1.99E+08	1.05E-01	3.05E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PI/CVC WITH ANR OFF MEAN - ONE SIGMA VALUES	0.125	0.25	0.5	1	2	4	8				P	O	M	PI/CVC WITH ANR OFF MEAN - ONE SIGMA VALUES	
	-9.2	-16.2	-21.3	-27	-34.2	-38.9	-39.9							UPDATED 1/01	
	0	0	0	0	0	0	0							TO ADJUST FOR FOAM SEALS	
	4.05E-02	1.23E+05	1.02E+06	1.70E+03	1.91E+06	5.62E+02	3.12E-01	4.44E+02	1.06E+07	5.50E-03	2.43E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PI/CVC WITH ANR ON MEAN - ONE SIGMA VALUES	0.125	0.25	0.5	1	2	4	8				P	O	M	PI/CVC WITH ANR ON MEAN - ONE SIGMA VALUES	
	-21	-25.6	-26.3	-24	-35.2	-37.9	-40.2							UPDATED 1/01	
	0	0	0	0	0	0	0							TO ADJUST FOR FOAM SEALS	
	4.05E-02	1.00E+05	3.04E+06	3.11E+02	1.03E+07	1.30E+03	5.67E-01	1.22E+03	6.58E+06	2.64E-03	1.88E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
QUIETPRO PASSIVE MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	P	QUIETPRO PASSIVE MEAN VALUES	
	-24	-30	-34	-42	-37	-33	-42							AFRL-RH-WP-TR-2009-0031	
	0	0	0	0	0	0	0							ANSI 12.6-1997	
	1.03E+01	4.17E+07	7.37E+10	1.38E+07	7.37E+09	1.38E+06	3.08E+02	9.98E+05	3.77E+09	3.51E+00	4.06E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
RACAL RAPTOR PASSIVE MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	M	RACAL RAPTOR PASSIVE MEAN VALUES	
	-9	-6	-7	-24	-28	-35	-35							AFRL-RH-WP-TR-2009-0031	
	0	0	0	0	0	0	0							ANSI 12.6-1997	
	4.05E-02	3.20E+05	7.94E+03	5.22E+02	1.00E+05	1.08E+03	8.10E+03	5.09E+04	1.87E+07	1.02E-02	4.40E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SILAFLEX MEAN - ONE SIGMA VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	SILAFLEX MEAN - ONE SIGMA VALUES	
	-22	-18	-20	-21	-29	-43	-43	-41	-34					MIL-HDBK-759 12 MAR 1975 P.403	
	0	0	0	0	0	0	0	0	0						
	1.03E+01	1.00E+08	7.15E+09	1.83E+06	7.15E+08	1.83E+05	1.58E+03	4.03E+05	3.15E+10	1.25E+01	6.29E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SILYNX QUIETOPS + FOAM MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	D	SILYNX QUIETOPS + FOAM MEAN VALUES	
	-25	-26	-29	-35	-35	-38	-44							AFRL-RH-WP-TR-2009-0035	
	0	0	0	0	0	0	0							ANSI 12.6-1997	
	4.05E-02	1.10E+05	1.48E+07	4.36E+02	1.49E+06	1.30E+03	1.56E+01	4.43E+03	1.83E+07	1.64E-02	2.20E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SILYNX QUIETOPS + TRIPLE FLANGE MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	D	SILYNX QUIETOPS + TRIPLE FLANGE MEAN VALUES	
	-16	-16	-18	-25	-28	-29	-37							AFRL-RH-WP-TR-2009-0035	
	0	0	0	0	0	0	0							ANSI 12.6-1997	
	4.05E-02	4.47E+05	6.91E+06	1.79E+03	1.79E+06	2.18E+03	7.83E+01	5.91E+03	3.55E+07	3.76E-02	4.65E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SKULL SCREWS MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	SKULL SCREWS MEAN VALUES	
	-38.2	-37.7	-39.9	-40.2	-38.1	-45	-46.9	-48.3	-45.6					30 MAY 2012 EMAIL	
	0	0	0	0	0	0	0	0	0					ANSI S3.1 1974 EARCAL	
	1.03E+01	2.83E+07	2.80E+10	2.18E+06	2.80E+09	2.18E+05	3.87E+07	3.31E+08	1.59E+10	6.60E+00	1.23E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
SPH-4 + EAR MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	D	SPH-4 + EAR MEAN VALUES	
	-32.7	-36.9	-42.4	-37.2	-37.5	-50.7	-54.8							USAARL 93-10 JANUARY 1993	
	0	0	0	0	0	0	0								
	4.05E-02	1.00E+05	1.23E+07	8.35E+02	1.54E+07	1.10E+03	1.51E+00	1.17E+03	9.99E+07	6.85E-02	1.05E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SPH4 + SINGLE FLANGE MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	D	SPH4 + SINGLE FLANGE MEAN VALUES	
	-27.5	-29.5	-34.4	-32.1	-38.3	-49.6	-55.3							USAARL 93-10 JANUARY 1993	
	0	0	0	0	0	0	0								
	4.05E-02	1.00E+05	5.45E+06	7.98E+02	1.87E+07	2.29E+03	8.08E-01	2.34E+03	9.99E+07	9.03E-02	1.20E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SPH4 + TRIPLE FLANGE MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	D	SPH4 + TRIPLE FLANGE MEAN VALUES	
	-30.6	-33.3	-36.2	-32	-38.6	-49	-53.6							USAARL 93-10 JANUARY 1993	
	0	0	0	0	0	0	0								
	4.05E-02	1.47E+05	6.91E+06	1.12E+03	6.91E+07	1.09E+04	4.63E+00	2.01E+03	1.46E+08	1.32E-01	1.76E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SPH-4 HELMET MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	M	SPH-4 HELMET MEAN VALUES	
	-17.2	-15	-30.2	-28.6	-34.9	-41.9	-44							USAARL 93-10 JANUARY 1996	
	0	0	0	0	0	0	0								
	4.05E-02	1.00E+05	6.46E+05	1.07E+03	6.46E+06	2.75E+02	2.53E-01	7.48E+02	1.28E+07	9.46E-03	2.32E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
STANDARD DOUBLE MEAN - ONE SIGMA VALUES	0.125	0.25	0.5	1	2	4	8				P	U	OD	STANDARD DOUBLE MEAN - ONE SIGMA VALUES	
	-21.7	-21.7	-28.4	-29.3	-34.3	-42.6	-39.8								
	0	0	0	0	0	0	0								
	4.05E-02	1.44E+05	7.87E+06	8.36E+02	1.98E+07	3.63E+03	1.61E-01	1.53E+03	2.55E+07	1.50E-02	2.49E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
STANDARD MUFF MEAN - ONE SIGMA VALUES	0.125	0.25	0.5	1	2	4	8				P	U	OM	STANDARD MUFF MEAN - ONE SIGMA VALUES	
	-13.6	-14.7	-16.4	-18.3	-26.3	-32.6	-31.3								
	0	0	0	0	0	0	0								
	1.03E+01	1.00E+08	5.69E+09	1.75E+06	5.69E+08	1.75E+05	6.09E+02	8.86E+05	5.65E+09	2.28E+00	9.31E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
STANDARD PLUG MEAN - ONE SIGMA VALUES	0.125	0.25	0.5	1	2	4	8				P	U	OP	STANDARD PLUG MEAN - ONE SIGMA VALUES	
	-13.6	-14.7	-16.4	-18.3	-26.3	-32.6	-31.3								
	0	0	0	0	0	0	0								
	1.03E+01	1.00E+08	5.69E+09	1.75E+06	5.69E+08	1.75E+05	6.09E+02	8.86E+05	5.65E+09	2.28E+00	9.31E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SUREFIRE EP3 CLOSED VALVE MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	SUREFIRE EP3 CLOSED VALVE MEAN VALUES	
	-31.1	-29.9	-33.9	-31.2	-35.6	-37.5	-33.6	-41.8	-43.5					MICHAEL & ASSOCIATES	
	0	0	0	0	0	0	0	0	0					ANSI S3.19-1974 MICHAEL & ASSOCIATES	
	1.03E+01	1.00E+07	9.90E+09	6.75E+05	9.90E+08	6.75E+04	2.53E+07	1.59E+08	8.85E+08	1.02E+00	1.86E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SUREFIRE EP4 CLOSED VALVE MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	SUREFIRE EP4 CLOSED VALVE MEAN VALUES	
	-30.5	-27.7	-31.4	-29	-36.3	-37.8	-32.8	-38.7	-41					MICHAEL & ASSOCIATES	
	0	0	0	0	0	0	0	0	0					ANSI S3.19-1974 MICHAEL & ASSOCIATES	
	1.03E+01	1.05E+07	7.60E+09	5.93E+05	7.60E+08	5.93E+04	2.48E+06	2.77E+07	7.35E+08	6.91E-01	1.77E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TACTICAL 6-S HEADSET MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	TACTICAL 6-S HEADSET MEAN VALUES	
	-12.3	-14.8	-25	-33.8	-30.4	-34.9	-38.6	-39	-36.1					WWW.AEARO.COM	
	0	0	0	0	0	0	0	0	0						
	4.05E-02	1.86E+05	2.32E+07	4.87E+02	1.87E+07	1.29E+03	1.47E-01	7.76E+02	3.29E+07	1.40E-02	2.73E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Oct.Band	Category	Status	Style	Configuration	
& Configuration	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.	Atten.				Data Source	
	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.	S.D.				Notes	
TCAPS + PASGT MEAN NO ANR - ONE SIGMA VALUES	0.125	0.25	0.5	1	2	4	8				P	O	M	TCAPS + PASGT MEAN NO ANR - ONE SIGMA VALUES	
	-5	-9.9	-9.6	-16.7	-19.5	-31.2	-24.7							22 OCT 1994 AF ARMSTRONG LAB	
	0	0	0	0	0	0	0								
	4.05E-02	9.12E+05	3.68E+06	1.05E+03	2.35E+06	2.21E+03	2.31E+00	1.67E+03	5.04E+07	2.03E-02	4.08E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TCAPS + PASGT WITH ANR ON MEAN - ONE SIGMA VALUES	0.125	0.25	0.5	1	2	4	8				P	O	M	TCAPS + PASGT WITH ANR ON MEAN - ONE SIGMA VALUES	
	-13.2	-18.2	-14.3	-17.4	-20.6	-30.2	-25							22 OCT 1994 AF ARMSTRONG LAB	
	0	0	0	0	0	0	0								
	4.05E-02	8.13E+05	5.88E+06	8.13E+02	1.67E+07	4.27E+03	3.26E+00	2.98E+03	4.49E+07	1.81E-02	3.64E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TRIPLE FLANGE MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	TRIPLE FLANGE MEAN VALUES	
	-21.1	-21	-20.8	-21	-27.6	-30	-27.9	-35	-36.2						
	0	0	0	0	0	0	0	0	0					5/21/97 USAARL DATA	
	1.03E+01	7.94E+07	8.22E+09	1.59E+06	8.22E+08	1.59E+05	1.31E+03	9.93E+05	3.21E+09	3.87E+00	9.31E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
V-51R SINGLE FLANGE MEAN VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	P	V-51R SINGLE FLANGE MEAN VALUES	
	-20.7	-19.2	-20.5	-21.4	-26.7	-28.8	-26	-29.9	-27.9						
	0	0	0	0	0	0	0	0	0					5/21/97 USAARL DATA	
	1.03E+01	1.00E+08	1.30E+10	3.25E+06	1.30E+09	3.25E+05	6.51E+03	1.81E+06	3.21E+09	1.31E+00	7.56E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
VIS CVC MEAN VALUES	0.063	0.125	0.25	0.5	1	2	4	8			P	U	M	VIS CVC MEAN VALUES	
	-9.3	-12.1	-18.8	-23.1	-31.5	-32.3	-42.5	-43.6						~1995 MEMO TO UPDATE 1994 VIS CVC INFO	
	0	0	0	0	0	0	0	0							
	4.05E-02	1.32E+05	1.19E+06	9.60E+02	1.15E+07	3.44E+02	5.42E-01	8.78E+02	2.05E+07	1.59E-02	2.29E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B-3. Available hearing protection configurations showing octave band attenuation, standard deviations, and electroacoustic circuit values (continued).

Hearing Protector Type & Configuration	Oct.Band Atten. S.D.	Oct.Band Atten. S.D.	Oct.Band Atten. S.D.	Oct.Band Atten. S.D.	Oct.Band Atten. S.D.	Oct.Band Atten. S.D.	Oct.Band Atten. S.D.	Oct.Band Atten. S.D.	Oct.Band Atten. S.D.	Oct.Band Atten. S.D.	Category	Status	Style	Configuration Data Source Notes	
VIS CVC WITH ACTIVE ATTENUATION ON MEAN VALUES	0.125	0.25	0.5	1	2	4	8				P	U	M	VIS CVC WITH ACTIVE ATTENUATION ON MEAN VALUES	
	-24.4	-27.7	-29.1	-30.8	-31.9	-40.9	-43.4							~1995 MEMO TO UPDATE 1994 VIS CVC INFO	
	0	0	0	0	0	0	0								
	4.05E-02	1.00E+05	7.07E+06	2.69E+02	4.31E+06	1.75E+03	7.79E-01	2.79E+03	1.21E+07	8.58E-03	2.51E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
WAX COTTON EARPLUG MEAN - ONE SIGMA VALUES	0.125	0.25	0.5	1	2	3	4	6	8		P	U	P	WAX COTTON EARPLUG MEAN - ONE SIGMA VALUES	
	-24	-23	-24	-27	-39	-41	-24	-36	-33					MIL-HDBK-759 12 MAR 1975 P.403	
	0	0	0	0	0	0	0	0	0						
	1.03E+01	1.00E+08	9.64E+09	5.24E+06	9.64E+08	5.24E+05	1.58E+03	3.98E+05	3.15E+10	5.01E+01	1.26E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
WILSON 258 EARMUFF MEAN - ONE SIGMA VALUES	0.125	0.25	0.5	1	2	3.15	4	6.3	8		P	U	M	WILSON 258 EARMUFF MEAN - ONE SIGMA VALUES	
	-15	-19	-30	-41	-38	-39	-44	-37	-36					MIL-HDBK-759 12 MAR 1975 P.403	
	0	0	0	0	0	0	0	0	0						
	4.05E-02	1.00E+05	1.95E+07	4.56E+02	3.16E+07	3.01E+03	1.47E-01	5.94E+02	1.93E+07	9.24E-03	1.03E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

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Appendix C. Default Values and Definitions for all Coefficients Included in the File man.coe

Table C-1. Default values and definitions for all AHAAH calculation coefficients included in the file man.coe.

Coefficient	Default Value	Units	Description or Purpose
Alphar	1	unitless	Induction field coupling, real part; always 1
Alphai	0	unitless	Imaginary part of Induction field coupling strength; always 0
Betar	2	unitless	Radiation field coupling, real part; (0 to 3); 2 = normal incidence (90°), 1 = grazing incidence (0°), 0 = head-shadow incidence (270°)
Betai	0	unitless	Radiation field coupling, imaginary part; usually 0
Rdf	1.29E-01	$dyne.sec.cm^{-5}$	Head diffraction radiation resistance
Ldf	2.56E-05	$g.cm^{-4}$	Head diffraction inductive mass
L1	2.215	cm	Length of cylindrical ear canal
L2	6.96E-01	cm	Length of exponential horn concha
S1	0.44	cm^2	Area of ear canal entrance; throat of exponential horn
S2	4.3	cm^2	Area of concha entrance; mouth of exponential horn
Lh	1.40E-02	$g.cm^{-4}$	Air-plug mass in narrow passages between tympanic cavity and remainder of middle-ear cavities
Cb	5.10E-06	$cm^5.dyne^{-1}$	Compliance of the antrum and the pneumatic cells
Rh	91.85	$dyne.sec.cm^{-5}$	Loss in narrow passages between tympanic cavity and remainder of middle-ear cavities
Cm	3.50E-07	$cm^5.dyne^{-1}$	Compliance of middle-ear cavities; bulla volume in cm^3/ (rho * c^2)
Lds	4.60E-03	$g.cm^{-4}$	Nonconductive eardrum mass (assoc. with mode of vibration); Ad = 0.55cm^2
Rds	1.147E+03	$dyne.sec.cm^{-5}$	Nonconductive eardrum loss (assoc. with mode of vibration) mechanical resistance(dyne/(cm/sec))/Ad^2
Cds	3.95E-07	$cm5.dyne^{-1}$	Compliance of nonconductive part of eardrum
Ldm	2.20E-02	$g.cm^{-4}$	Mass of conductive part of eardrum and malleus for mode of vibration
Cdc	2.31E-06	$cm^5.dyne^{-1}$	Compliance of conductive part of eardrum and suspensory ligaments of ossicular chain
Rdc	60.6	$dyne.sec.cm^{-5}$	Loss of conductive part of eardrum and ossicles
Nt	20	unitless ratio	Turns ratio of transformer of middle ear = Astapes*Li/(Ad*Lm) Astapes = 0.021 cm^2 stapes area
Rmi	8.39E+05	$dyne.sec.cm^{-5}$	Loss of the malleo-incudal joint
Cmi	4.33E-10	$cm5.dyne^{-1}$	Compliance of the malleo-incudal joint
Li	2.44	$g.cm^{-4}$	Mass of incus
Ris	4.75E+04	$dyne.sec.cm^{-5}$	Loss of the incudo-stapedial joint
Cis	4.57E-10	$cm^5.dyne^{-1}$	Compliance of the incudo-stapedial joint
Ls	2.44	$g.cm^{-4}$	Mass of stapes
Lv	6.25	$g.cm^{-4}$	Mass of perilymph in vestibule between stapes and basal end of basilar membrane
Lo	52.4	$g.cm^{-4}$	Mass of perilymph in helicotrema

Note: All values in this table are given as specific acoustic quantities. Ear protection property values in the man.coe file have been superseded by values in the HPD Atten.txt file. For additional details on the function of these parameters, see Price, G. R.; Kalb, J. T. Insights Into Hazard From Intense Impulses From a Mathematical Model of the Ear. *J. Acoust. Soc. Am.* **1991**, *90*, 219–227.

Table C-1. Default values and definitions for all AHAAH calculation coefficients included in the file man.coe (continued).

Coefficient	Default Value	Units	Description or Purpose
Ral	2.06E+05	dyne.sec.cm^{-5}	Resistance of annular ligament linear for stapes displacements <10 microns
Rc	2.64E+06	dyne.sec.cm^{-5}	Resistance at base of cochlea
Ro	1.80E+05	dyne.sec.cm^{-5}	Resistance of perilymph in helicotrema
Cal	4.90E-10	cm^5.dyne^{-1}	Compliance of annular ligament; linear for stapes displacements <10 microns
Crw	1.38E-08	cm^5.dyne^{-1}	Compliance of round window
Astapes	2.10E-02	cm^2	Effective area of stapes footplate
Lgap	30	µm	Gap width of annular ligament
Eo	0.01	unitless	Equilibrium strain of annular ligament filaments
Eb	0.2	unitless	Breaking strain of annular ligament filaments
Ramp	6	unitless ratio	Ratio of resistance to stiffness of annular ligament at high loads
So	1.00E+09	dyne.cm^{-3}	Basilar membrane mechanical stiffness per unit area at base
Mo	0.0058	g.cm^{-3}	Effective mass of basilar membrane and vertically moving fluid, per unit area, at base of basilar membrane
Rvo	91.2	dyne.sec.cm^{-3}	Basilar membrane viscous-resistance per unit area at base
Bo	0.008	cm	Width of basilar membrane at base
Ao	0.0125	cm^2	Effective scala cross-section area = Sv*St/(Sv+St)
Fo	20000	Hz	Maximum audible frequency associated with motion at base of basilar membrane
Delo	0.03	unitless	Loss constant at base of basilar membrane full-width-at-half-maximum/characteristic freq
D1	0.666	cm	S(x)=So exp(-x/D1) stiffness decrement characteristic length D1=1/(2/Dc-1/D2)
D2	1	cm	M(x)=Mo exp(x/D2) mass increment characteristic length (D2=D4/2)
D3	1	cm	R(x)=Rvo exp(x/D3) resistance increment characteristic length (D3=D4/2)
D4	2	cm	B(x)=Bo exp(x/D4) basilar membrane width increment characteristic length
D5	2	cm	A(x)=Ao exp(-x/D5) Scala area decrement characteristic length (D5=D4)
Dc	0.8	cm	F(x)=Fo exp(-x/Dc) characteristic length for resonant frequency
Nw	2.0	unitless	Number of wavelengths of the wave on the basilar membrane
Ca	0.5	unitless	Cochlear amplifier gain (from 0.1 to 10)
Bcoef	2	unitless	Bcoef stress fatigue power-law coefficient
XbApex	3.5	cm	Length of cochlea from base to apex
XbmFrom	0.425	cm	Starting distance from base of basilar membrane
XbmTo	3.175	cm	Ending distance from base of basilar membrane
XbmNo	23	unitless	Number of analysis locations on basilar membrane

Note: All values in this table are given as specific acoustic quantities. Ear protection property values in the man.coe file have been superseded by values in the HPD Atten.txt file. For additional details on the function of these parameters, see Price, G. R.; Kalb, J. T. Insights Into Hazard From Intense Impulses From a Mathematical Model of the Ear. *J. Acoust. Soc. Am.* **1991**, *90*, 219–227.

Table C-1. Default values and definitions for all AHAAH calculation coefficients included in the file man.coe (continued).

Coefficient	Default Value	Units	Description or Purpose
SweightBase	1.0	unitless	Stress weighting at base of cochlea X = 0
SweightApex	1.0	unitless	Stress weight at apex of cochlea X = Xbapex
Damage Threshold	0	cm	Damage Threshold, displacement threshold on basilar membrane at which damage begins
MemDelay	9.00E-03	seconds	Activation time of aural reflex relative to arrival of sound for unwarned ear is 9.0E-3 s; for the warned ear this is always set to -50.0E-3 s by the program
MemTimeConst	1.17E-02	seconds	Rise-time constant after activation of aural reflex
MemMagK	12	unitless	Stiffness after divided by stiffness before activation of aural reflex
MemMagR	12	unitless	Loss after divided by loss before activation of aural reflex
AdaptFactor	2.5	unitless	Relaxation factor in auto-adaptive step-size algorithm in middle ear integrator
CochlearGainFactor	0.0724	unitless	WKB multiplicative factor (0.15 for WKBOrig) (0.025 for WKBTaper)
WkbScalaBMwidthDecay	0.75	cm^{-1}	WKB characteristic decay inverse-length based on tapering factors
CochlearModelType	2	nominal value	CochlearModelType: 3 = WKB No Taper, 2 = WKB Taper, 1 = WKB Untapered
MakeXfrFile	0	nominal value	Store calculated transfer function: 1 = Yes, 0 = No (not used)
PrintHazTable	1	nominal value	Store distances, frequency locations and hazards in cochlea: 1 = Yes 0 = No
SaveBMD	0	nominal value	Store basilar membrane displacement waveforms: 1 = Yes 0 = No (not used)
SaveSTD	0	nominal value	Store stapes displacement waveforms: 1 = Yes 0 = No (not used)
MultiGraph	0	nominal value	MultiGraph: 1 = Yes 0 = No (not used)
Earplug	0	nominal value	Apply Earplug: 1 = Yes 0 = No (not used)
HeadPhone	0	nominal value	Apply Earmuff: 1 = Yes 0 = No (not used)
HornExtEar	1	nominal value	Choice of external ear geometry model: 1 = Exponential Horn, 0 = Three-cylinders
Tm3Piston	1	nominal value	Eardrum model: 1 = Two pistons (three-piston model not used)
TerminateCochlea	0	nominal value	Cochlear termination choice: 1 = infinite length, 0 = finite length
Ccush	9.00E-06	$cm^5.dyne^{-1}$	Earmuff cushion properties (not used in man.coe) See values in HPD Atten.txt
Rcush	540	$dyne.sec.cm^{-5}$	Earmuff cushion properties (not used in man.coe) See values in HPD Atten.txt
Cskin	0.000015	$cm^5.dyne^{-1}$	Skin compliance properties (not used in man.coe) See values in HPD Atten.txt
Rskin	250	$dyne.sec.cm^{-5}$	Skin resistance properties (not used in man.coe) See values in HPD Atten.txt
Lleak	2.00E-03	$g.cm^{-4}$	Earmuff leakage (not used in man.coe) See values in HPD Atten.txt

Note: All values in this table are given as specific acoustic quantities. Ear protection property values in the man.coe file have been superseded by values in the HPD Atten.txt file. For additional details on the function of these parameters, see Price, G. R.; Kalb, J. T. Insights Into Hazard From Intense Impulses From a Mathematical Model of the Ear. *J. Acoust. Soc. Am.* **1991**, *90*, 219–227.

Table C-1. Default values and definitions for all AHAAH calculation coefficients included in the file man.coe (continued).

Coefficient	Default Value	Units	Description or Purpose
Rleak	3.0	dyne.sec.cm^{-5}	Earmuff leakage loss (not used in man.coe) See values in HPD Atten.txt
Lcup	0.04	g.cm^{-4}	Earmuff mass (not used in man.coe) See values in HPD Atten.txt
Ccup	0.00007	cm^{5}.dyne^{-1}	Compliance of volume under earmuff (not used in man.coe) See values in HPD Atten.txt
Rmat	2.0	dyne.sec.cm^{-5}	Earmuff material properties (not used in man.coe) See values in HPD Atten.txt
Lmat	0.000056	g.cm^{-4}	Earmuff material properties (not used in man.coe) See values in HPD Atten.txt
Cmat	0.000007	cm^{5}.dyne^{-1}	Earmuff material properties (not used in man.coe) See values in HPD Atten.txt

Note: All values in this table are given as specific acoustic quantities. Ear protection property values in the man.coe file have been superseded by values in the HPD Atten.txt file. For additional details on the function of these parameters, see Price, G. R.; Kalb, J. T. Insights Into Hazard From Intense Impulses From a Mathematical Model of the Ear. *J. Acoust. Soc. Am.* **1991**, *90*, 219–227.

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Appendix D. Chronologically Organized List of Selected Publications and Presentations on Noise and Modeling Associated With the Development and Use of Auditory Hazard Assessment Algorithm for Humans (AHAAH)*

*This appendix appears in its original form, without editorial change.

2013

Kalb J. T. (2013). An Electroacoustic Hearing Protector Simulator that Accurately Predicts Pressure Levels in the Ear Based on Standard Performance Metrics; ARL-TR-6562; U.S. Army Research Laboratory, Aberdeen Proving Ground, MD.

2012

Amrein, B.E. and Letowski, T.R. (2012). <u>High level impulse sounds and human hearing: Standards, physiology, quantification</u>, ARL Technical Report ARL-TR-6017, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD.

Amrein, B.E. and Letowski, T.R. (2012). Military noise limits: How much is too much?, *Proceedings of the 41st International Congress and Exposition on Noise Control Engineering* (Inter-Noise 2012), New York.

Price, G.R. (2012). "Impulse noise hazard: From theoretical understanding to engineering solutions." Noise Control Engineering Journal, 60 (3), pp. 301-312.

2011

Amrein, B.E. and Letowski, T.R. (2011). <u>Predicting and ameliorating the effect of very intense sounds on the ear: the auditory hazard assessment algorithm for humans (AHAAH)</u>, In NATO RTO (2011) *A survey of blast injury across the full landscape of military science.* Technical Report TR-HFM-207, Neuilly-Sur-Seine (France): NATO.

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Kalb, J. T. (2011). Modeling the reduction of impulse noise hazard by hearing protectors, (2011) *Proceedings of the Forum Acusticum 2011*, pp. 723-728. Aalborg (Denmark); Forum Acusticum.

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